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The Spectral Changes of a Typical Nova

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Introduction

In previous papers of this series[1] several aspects of the nova problem have been discussed. In those papers some incidental references have been made to spectroscopic evidence. It is now in order to give an organized account of the spectroscopic history of a typical nova.

No one star is typical of the nova class; each one has some individual eccentricity. In the following account we shall make occasional reference to specific stars as examples, but for the most part we are concerned with an ideal or abstraction,—a composite of many individuals. In line with this point of view, the accompanying "spectrograms" in Plates II and III have been prepared.[2] They are not rigorously accurate as to wave-lengths of lines; perhaps they are more artistic than scientific. But they do picture pretty faithfully, in a qualitative sense, the appearance of typical nova spectra at a number of stages.

No time scale is given with Plates II and III. Instead, each "spectrum" is designated in terms of the number of magnitudes below maximum. This is permissible because, in the main, the stage of spectral development is closely connected with the light variations. If the light declines rapidly, the spectrum changes rapidly; and slow decline of light is associated with slow change of spectrum. Save for some systematic individual differences, the spectra of novae are all rather similar at any given number of magnitudes below maximum.[3] The greatest deviations were those of Nova Cygni 1920 and Nova Puppis 1942, both of which faded in light somewhat more rapidly than their spectral development called for.

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[1] The Light Curves of Novae, Popular Astronomy, **47**, 410, 481, 538, 1939.
The Physical Condition of Pre-nova Stars, *Ibid.*, **49**, 292, 1941.
Neutrinos and Novae, *Ibid.*, **49**, 457, 1941.
The Luminositics of Novae, *Ibid.*, **50**, 233, 1942.

[2] The "spectrograms" were made as follows. Each continuous spectrum was first prepared with black crayon,—heavy or light, as desired,—smudged about uniformly with a stump (a pointed roll of soft paper). Absorption lines were then produced by a stroke of the eraser, and were touched up as necessary with additional crayon and shaded with the stump. Emission bands were drawn in with the crayon upon the already prepared background, and they could be made either sharp-edged or as hazy as desired by use of the stump. The resulting picture was a negative (dark emission and white absorption), from which the positive was obtained photographically.

[3] McLaughlin, *Aph. J.*, **85**, 362, 1937; **95**, 428, 1942.

In order to relate the "spectra" in Plates II and III to a time scale, we give in Table 1 the time intervals from the date of maximum for each

TABLE 1

DURATION (IN DAYS) OF DECLINE THROUGH ΔM MAGNITUDES FROM MAXIMUM

	Nova Persei	Nova Gemin.	Nova Aquilae	Nova Pictoris	Nova Lacertae	Nova Puppis	Plate II V=1500	Plate III V=1000
Δm	1901	1912	1918	1925	1936	1942	km/sec	km/sec
1.0	2.5	1.5	0.5	12	2.1	2.5	2	5
2.0	7	10	3.0	70	4.5	4	4	10
3.0	13	35	6.5	150	9	8	8	20
4.0	28	83	14	290	20	13	15	40
5.0	60	360	38	800	48	19	40	90
6.0	180	490	92	1200	91	30	90	200

integral number of magnitudes decline for several of the brighter novae.[4] In the last two columns of the table, the time scales are given for Plates II and III, corresponding to the indicated principal absorption velocities of —1500 and —1000 km/sec, respectively.

SPECTRA IN THE PRE-NOVA-STAGE

There is no good record of the pre-outburst spectrum of any past nova. Although the spectrum of Nova Aquilae 1918 is often said to have been of class A before the outburst, there is nothing in the observation to conflict with the suggestion that it may have been simply continuous, with an energy distribution like that of an O-type star, and like that of some post-nova stars.

The author has discussed the probable similarity of pre- and post-nova stars in two previous papers of this series. Humason[5] observed the spectra of a number of old novae and found that about half of them were purely continuous, and that the rest had more or less conspicuous emission lines of hydrogen and HeII. The continuous spectra showed considerable extent in the violet, indicating high temperature, and the low luminosity requires that the stars be small and pretty dense,—in short, subdwarfs. The equality of luminosity before and after the flare-up then requires that the pre-nova star be of similar constitution.

Perhaps it is not stretching a point to refer to the spectra of repeating novae at minimum. A Michigan spectrogram of RS Ophiuchi, nine years after its 1933 flare-up, shows a spectrum quite similar to that of ten years before the outburst: a continuous spectrum with strong hydrogen and weak iron emission. The chief point of difference is the occurrence of strong HeII emission in 1942, but not in 1923. In the case of T Pyxidis, which has had three outbursts, a spectrum taken by Humason in 1934 shows bright HeII and hydrogen on a continuous spectrum, closely similar to any one of several old novae. But, unless we make the improbable assumption that T Pyxidis will never again flare

[4] The data refer to smoothed light curves, drawn so as to average the secondary variations, if any.

[5] *Aph. J.*, **88**, 228, 1938.

up, we must admit that it was then in the pre-nova stage of an outburst yet to come. As spectral surveys go to fainter limiting magnitudes, the chance of getting a pre-nova observation increases. At present we can only say that it is inferred that pre-nova stars are rather dense hot subdwarfs, very similar to the post-nova objects, and that any other hypothesis encounters very serious difficulties. It might be added that known subdwarfs and white dwarfs will bear watching.

The Rise to Maximum

We have not yet been so fortunate as to record the spectrum of any nova as much as three magnitudes below maximum during the increase of light. The reason for this lies in the extreme rapidity of the rise, and consequent failure to discover the star until it was at or near the "pre-maximum halt." Even the slow novae rise very suddenly to within about two magnitudes of maximum.

Our positive knowledge of nova spectra, then, begins about two magnitudes below maximum on the rise. At that stage the spectrum has usually been continuous, with broad and diffuse,—sometimes very faint and vague,—absorption lines, strongly displaced towards the violet. Some novae have shown weak hazy emission bands of hydrogen at this stage; but only one, Nova Herculis, had numerous strong bright bands. In all cases the emissions were approximately undisplaced and carried the absorption lines on their violetward edges.

The first observed absorption spectrum is usually of late class B or early class A, and commonly shows decided peculiarities. If the ratio of MgII to HeI were used, the spectral classes of Nova Persei and Nova Lacertae 1936 would be called B9, but lines of OII and NII were present in both, and these are ordinarily found only in the earlier subdivisions of class B. Nova Herculis had the most marked B-type spectrum, perhaps B3-B5, and had conspicuous emission bands of HeI, CII, and NII. The other bright novae were A0 or later when they were first observed.

During the final rise to greatest brilliance, the absorption spectrum usually shows marked changes. In the six best-observed stars, the type has grown distinctly later, implying a cooling of the effective absorbing atmosphere. The limited available evidence indicates that the energy distribution in the continuous spectrum changes in the same sense. Another well-marked change is a real increase in the strength of most absorption lines, and a definite tendency to become better defined as maximum is approached. This was especially striking in Nova Herculis, whose lines changed from very broad and diffuse to rather narrow, strong, and definitely edged. The bright lines normally show a relative weakening as the star rises to maximum, and disappear at maximum light. However, Nova Herculis still showed conspicuous Hα emission.

An attempt has been made to exhibit these changes in the first two spectra on Plates II and III. At maximum light the spectrum strongly

resembles that of a supergiant star of class A or F. Close similarity to the spectrum of α Cygni has often been noted, and in other cases the spectrum of ϵ Aurigae has been closely matched. Thus, Nova Aquilae 1918 was A5, Nova Lacertae 1936 was A2, Nova Herculis resembled class cA8-F0, and Nova Persei was A0. Throughout these changes the absorption lines remain strongly displaced towards the violet. In most stars no marked change of displacement has been recorded; in Nova Aquilae a definite small decrease of displacement was observed, and in Nova Herculis a very marked reduction of shift occurred. In that case the redward edge of the wide emission shrank inward towards the normal position, so that the bright lines narrowed without much displacement of their centers.

The Post-Maximum Transformation

Just after maximum the sequence of events is so rapid in the fastest novae that the precise course of development of the absorption spectrum is not always clear. In the slower novae, Nova Herculis, Nova Pictoris, and even Nova Geminorum, the type continued to get later as the light declined. Thus, three days after maximum, Nova Herculis was class cF5; Nova Geminorum one day after maximum was also cF5.

Up to this point we have been concerned with a single system of absorption lines. Because this set originates during the increase of light and disappears soon after maximum, we shall speak of it as the "pre-maximum spectrum." The name must not be taken to imply that it disappears before the decline sets in. Actually it has been observed to endure for from one to several days after maximum light in every case where the record was adequate.

Shortly after maximum,—a few hours in fast novae and a few days in slow ones,—there occurs a transformation which has not been universally recognized. It has usually been assumed that the absorption spectrum that was present before and at maximum develops into the strong absorption spectrum which endures for a number of days or even weeks after maximum. But such an interpretation is incorrect. In both Nova Herculis and Nova Pictoris the sequence of events was quite clear; the pre-maximum spectrum was *replaced* by one with a somewhat greater shift towards the violet, and for a few days both sets of absorption lines were present simultaneously. In Nova Geminorum the first spectrum almost completely disappeared before the second one emerged. In Nova Lacertae 1936 and Nova Aquilae 1918, most investigators failed to separate these two spectra, but Michigan spectrograms of both stars show the two sets of lines. The rapidity of the changes, however, served to obscure the course of development, and in Nova Lacertae the diffuse lines blended badly in some parts of the spectrum.

The double-lined stage at the middle of the transformation is represented in the third strips of Plates II and III. This replacement of one

spectrum by another of larger displacement now appears to be a standard procedure of both fast and slow novae. Where the record is sufficiently detailed, it appears that the hydrogen lines of the old (pre-maximum) spectrum last for some time after most of its metallic lines, but *H* and *K* of CaII endure longest of all, and the *D* lines of NaI accompany them.

The new absorption spectrum that emerges just after maximum is called the *"principal spectrum."* In most cases its type is pretty similar to that of the spectrum it replaces, or later than the type at maximum. Thus, we have Nova Herculis of class cF5, Nova Pictoris cF8, Nova Aquilae cF5 (or perhaps cF2), Nova Lacertae F2, Nova Cygni F2, Nova Geminorum poorly defined A5.

Usually the pre-maximum spectrum disappears as soon as the principal spectrum has become well-developed. In Nova Pictoris and Nova Lacertae, however, the pre-maximum spectrum lingered with much reduced intensity for a considerable interval after maximum.

The Supergiant Stage

For a relatively brief interval, in the usual case, the principal absorption is the only dark-line spectrum present, at about one magnitude below maximum on the declining branch of the light curve. This phase of the spectrum is shown in the fourth strips of Plates II and III. It has often been called the "Alpha Cygni stage," because of the close resemblance to the spectrum of that supergiant star in some cases. About as often, however, the spectrum of ϵ Aurigae is rather faithfully copied. The writer suggests the use of the term "supergiant stage," since it implies less restriction to a definite spectral type, but expresses the high-luminosity character of the spectrum.

Simultaneously with the emergence of the principal absorption spectrum, widened emission lines,—the so-called "bands,"—make their appearance. It is an invariable rule that these bands are spread symmetrically about their normal positions. Their violetward edges are marked by the absorption lines of the principal spectrum; their redward edges show nearly equal displacements from the normal positions of the lines. The bands of hydrogen are always the most prominent at first. Emission at *H* and *K* of CaII is usually conspicuous, and FeII is always well represented. In slow novae, whose absorption velocities are low and whose bands are therefore relatively narrow, many other emissions of ionized metals appear, but they are less intense than those of hydrogen, CaII, and FeII.

At about this stage the forbidden emission lines of OI commonly appear, but they remain rather weak for a time. With the decline of light from maximum, all the emission bands show up in better contrast with the continuum.

Table 2 gives a summary of the main facts concerning the spectral class and absorption velocities of the pre-maximum and principal

TABLE 2

SPECTRAL CLASSES AND VELOCITIES OF EARLY ABSORPTION SPECTRA

	Pre-maximum spectrum				Principal spectrum	
	Class			Velocity		Velocity
Nova	before	at Max.	after	km/sec	Class	km/sec
Persei	B9p	A0	A2	— 700	A2:	—1270
Geminorum	A5	A5 ?	cF5	— 450	A5:	— 800
Aquilae	A0	A5	...	—1300	cF5	—1450
Cygni	A0	A2	A5:	— 400	gF0:	— 700
Pictoris	F2	gF8	gF8	— 70	gF8	— 285
Herculis	B5p	cF0	cF5	— 176	cF5	— 315
Lacertae	B9p	gA2	gA5:	—1300	gF0	—1500

spectra of seven bright novae. Data for Nova Puppis 1942 are not included because of insufficient precise information.

THE "DIFFUSE ENHANCED" ABSORPTION STAGE

When the light has declined about 1.5 magnitudes, another set of absorption lines comes in. This system always contains lines of hydrogen, CaII, and MgII, and usually the stronger lines of FeII are present. Lines of OI and NaI also are often found in this system. In the slow novae, whose lines are better defined, TiII, CrII, and other ionized metals appear. Because this spectrum is much more diffuse than the principal spectrum, and because lines of ionized atoms (the "enhanced" lines of old-time spectroscopy) show conspicuously in this system, the name *"diffuse enhanced spectrum"* was coined for it by the writer.[6] The displacements of this set are roughly twice as great as for the principal spectra, but in different novae the ratio of velocities is from 1.5 to 2.5. The hydrogen lines of the diffuse enhanced spectrum,—and sometimes those of FeII,—are accompanied by emission which is symmetrically broadened about the normal position, and which extends from the diffuse enhanced absorption line on its violet edge to a position equally displaced towards the red. With the principal band at the center of the broader diffuse enhanced emission, the resultant band profile has a form suggestive of the head and shoulders of a man protruding from behind a wall whose level top represents the strength of the continuous spectrum. The central intense block (the principal emission band) will be called the "core"; the outer weaker parts (the diffuse enhanced emission) will be called the "shoulders." The fullest development of the diffuse enhanced spectrum is shown in the sixth strips of Plates II and III, where its most prominent absorption lines are marked by vertical white dashes opposite the name "diffuse enhanced."

At their greatest strength, the absorption lines of the diffuse enhanced spectrum considerably exceed those of the principal spectrum, yet there are *fewer lines,* even of metals that have many lines in the principal spectrum. The explanation of this anomaly probably lies in the curve of growth. Due to very high turbulent velocities, which cause the dif-

[6] *Aph. J.*, **85**, 362, 1937.

fuseness of the spectrum, the line intensities are proportional to the number of atoms, even for the strongest lines. In the principal spectrum, on the other hand, turbulence is lower, and the strongest lines lie on the horizontal part of the curve of growth or the beginning of the square-root branch. Probably fewer atoms are involved in the production of the diffuse enhanced spectrum than the principal; this is suggested by the absence of the weaker lines. But, above a certain limiting number of atoms, turbulence makes them more effective absorbers, so that the strongest lines greatly exceed those of the principal set.

In the average case, the diffuse enhanced spectrum reaches its full development when the nova has dropped to about two magnitudes below maximum. It then begins to weaken; the CaII, NaI, and OI lines go out first, then FeII, and lastly hydrogen. Before their disappearance the hydrogen lines commonly separate into two or more rather well-defined components (these were quite sharp in Nova Herculis). These, with added components which may appear between the principal and diffuse enhanced lines, may give a group of as many as six closely spaced lines. This stage is readily recognized at a glance. Soon afterward the diffuse enhanced spectrum is gone. When it fades, the associated emission "shoulders" fade with it, leaving the "cores" of the emission bands standing alone.

The Orion Stage

At about the time the diffuse enhanced spectrum is strongest, another absorption spectrum begins to emerge. It has no lines in common with previous sets except the hydrogen lines in some cases. This new system is a diffuse set of lines of HeI, OII, NII, and CII. In some stars it has actually lacked hydrogen lines. This is conveniently designated the "Orion spectrum," since its prominent lines are those which are strong in such stars as ϵ and γ Orionis. Weak hazy emissions accompany many of these lines, and a few of these fuzzy bands,—notably the groups about λ 5680 and λ 4640,—are quite prominent when this spectrum is strongest. At their greatest strength the Orion lines may be almost as strong as those of the diffuse enhanced absorption. They attain their maximum intensity when the diffuse enhanced set is fading away or is in its conspicuously multiple stage.

The displacement of the Orion spectrum is towards the violet, as with all the absorption systems previously discussed, but the amount of its shift does not appear to be readily reducible to a simple relation to those of the other systems. In several novae its velocity has been roughly equal to that of the diffuse enhanced spectrum,—usually a little greater. In Nova Geminorum it was indeed regarded by Stratton and Wright as a part of the diffuse enhanced spectrum, though it sometimes disagreed by amounts sufficient to indicate an independent origin, in the opinion of the present writer. In Nova Herculis it was clearly quite separate, and gave a velocity intermediate between those of the

principal and the diffuse enhanced spectra, but another Orion set that popped up occasionally showed displacements greater than the diffuse enhanced. In Nova Cygni, Baldwin[7] showed that there was an Orion spectrum with a displacement much greater than that of the diffuse enhanced, and in Nova Aquilae also this was the case.

The Orion emission spectrum which accompanies these absorptions always has very hazy broad bands whose lack of structure and of recognizable edges contrast notably with the bands of the diffuse enhanced spectrum. However, it is plain that the fuzzy emissions are widened about their normal positions, and that the strongest ones have the corresponding absorption lines approximately at their violet extremities. This is most clearly evident at the band λ 5680 NII when it is most strongly developed (see Plate III, ninth strip). The hazy band at λ 4640 also belongs to this system, but it reaches its full development after the Orion absorption stage.

The Orion stage of the spectrum is represented in the eighth and ninth strips of Plates II and III, where its prominent lines are indicated by white marks opposite the name "Orion." This set of lines disappears rather quickly when the nova is a little more than three magnitudes below maximum. Just before they go, however, the NIII absorption lines, λλ 4097, 4103, usually appear. But to retain the narrative character of this account, we must pause now to review the behavior of the principal spectrum during the decline.

THE FADING OF THE PRINCIPAL SPECTRUM

During the rise and fall of the diffuse enhanced and Orion spectra, the principal absorption has been undergoing a remarkable and instructive transformation. When it first emerged, just after maximum light, it was almost a perfect replica of the spectrum of a supergiant like ε Aurigae or α Cygni. As one line after another drops out, the remaining pattern resembles less and less that of any normal spectral class. The closest counterparts are the "shell" spectra of some Be stars, or the spectrum of ζ Aurigae at the time when the atmosphere of the large cool star is interposed between the observer and the B-type component. The interpretation of the nova spectrum, like that of the others just mentioned, is doubtless to be found in the considerable dilution of the radiation that reaches the absorbing atmosphere. Struve[8] pointed out that the lines which persisted long in the principal spectrum of Nova Herculis were those whose lower levels are metastable. In particular, this is true of the lines of TiII and MgI, which endured after almost all others had disappeared. The hydrogen lines remain longest, which we may conjecture is due in part to the metastability of the 2s state. The *H* and *K* lines of CaII are long-lived because they arise from the ground

[7] *Mich. Obs. Publ.*, **8**, 88, 1940.

[8] *Proc. Amer. Philos. Soc.*, **81**, 225 *ff.*, 1939.

state. On the other hand, lines of OI and MgII disappear very early, since their lower levels have strong transitions to still lower energy states.

Near the end of their history, the principal spectra of some novae have developed absorption lines of HeI that were not present earlier. The lines that appear are those found in "shell" spectra: λλ 3889, 4026, 4472. The first is a singlet whose lower level is metastable. The other two are triplets, and owe their presence to a concentration of atoms in the triplet states, because of the metastability of the 2^3s state. These helium lines and the remaining hydrogen lines of the principal absorption spectrum fade away when the nova is about four magnitudes below maximum. The principal emission bands of hydrogen and other elements then remain standing alone, without the absorption that previously marked their violet edges.

During the absorption-line stages that have been summarized above, the emission bands have been playing a role whose importance increases as time passes and the light declines. All emissions tend to become more prominent with fading light, since the continuum is "dropping out from under them," but relative changes also are very conspicuous. At first the bright lines are those of hydrogen and FeII, with CaII and NaI, and sometimes permitted OI. The forbidden emissions of OI appear early and remain for a time at rather low intensity. But presently, about the time the Orion absorption lines are strong, the [OI] emissions strengthen rather rapidly at λλ 5577 (the auroral line), 6300, and 6363. This can be designated the "[OI] flash." Its position in the sequence of events is somewhat variable; in Nova Herculis it was early, and in the faster novae it occurred late. It is commonly followed (or sometimes accompanied) by a quick increase of λ 5755 [NII],—the "[NII] flash." Soon after this forbidden line has flared up, the permitted lines of NII also increase. Intensity ratios between forbidden and permitted NII lines thus go up and down rather quickly. A little later comes the "Helium flash," a quick strengthening of λ 5876 HeI, which suddenly replaces the NaI emission that was prominent in that part of the spectrum. These changes can be readily followed in Plate III, strips 6 to 11 inclusive. *All of these bands have widths that identify them as members of the principal spectrum,* though at certain stages some of them,—especially those of NII,—have wider hazy wings that indicate another origin *in addition* to the gases which give the principal spectrum. These hazy wings belong to the Orion system, already discussed above.

The "4640" Stage

Even before the Orion spectrum disappears, two strong diffuse lines six angstroms apart emerge to the violet of Hδ[9]. For a long time they were unidentified, but Baxandall pointed out some twenty years ago

[9] This is outside the range of spectrum covered in Plates II and III.

that they could be assigned to NIII, and this origin is now fully confirmed. They evidently belong to the Orion absorption system, since their displacements agree with those of the Orion lines, and they share variations of velocity exhibited by that system. But they are of higher excitation than most of the Orion lines, and they endure after the rest of them have disappeared. In Nova Aquilae 1918, the position of this pair of lines was subject to large fluctuations, which accompanied the secondary variations of light. At light maxima they were least displaced, near the minima they were most displaced, and *at* the minima they disappeared.

At about the same time, a great wide, diffuse, structureless emission band is steadily strengthening in the region between 4600 and 4700 A. It is commonly called "4640," and is due chiefly to NIII and perhaps CIII, though in its earliest stages OII and NII may be the chief contributors. Its maximum development is reached about the time of the helium flash, and while the strong NIII pair near Hδ is prominent, but after the rest of the Orion absorption spectrum has disappeared. A similar broad hazy radiation centered on Hδ is clearly due to NIII, and the absorption pair λλ 4097, 4103 lies at its violet edge. Both of these fuzzy emissions represent a higher-excitation continuation of the Orion emission system which accompanied the greatest strength of the Orion absorption lines. The broad and hazy "4640" band is shown in the ninth to eleventh strips of Plate II.

The NIII pair usually disappears with or shortly after the last remnants of the principal absorption, but not before another pair of dark lines has emerged, in the violet wing of the "4640" emission. These were identified by Wyse as λλ 4605, 4622 Nv. They accompanied the NIII lines in their fluctuations of position and endure after the latter have disappeared. They are shown strongest in the eleventh strip of Plate II. Their life is short, and no further dark lines have been found in the later history of any nova, save for interstellar absorptions.

THE NEBULAR STAGE

While "4640" is still in its fullest development, the "nebular"emission bands emerge faintly at λλ 5007, 4959, and 4363. These are forbidden lines of OIII. Their widths are equal to those of the emissions in the principal spectrum, and they show the same pattern of emission maxima and minima within their borders, though the relative strengths of features may differ from those in the hydrogen bands. In the main, they must originate in the same body of gas as that which produces the principal spectrum.

These nebular emissions strengthen rather steadily in novae whose decline of light is smooth. In those that show fluctuations during the "transition" stage of the light curve (Nova Aquilae 1918, Nova Persei 1901) the nebular lines have shown variations of strength which correlate closely with the light changes. Relatively to hydrogen, the

[OIII] lines fade at the subordinate maxima of light.

The two bands [NeIII] 3869, 3968, have been very strong in the spectra of a few novae, as Nova Persei 1901 and Nova Sagittarii 1936.7, and were possibly absent in a few others, as Nova Cygni 1920, but they are found in most cases when the record is adequate to permit a definite verdict. When they do occur, they strengthen along with the [OIII] emissions and remain strong throughout the nebular stage.

As the [OIII] emissions strengthen, the broad structureless diffuse emission at 4640 fades and uncovers a 4640 band of *normal* structure,—that is, a member of the principal spectrum, with width and structure like that of the hydrogen and nebular emissions. When the broad hazy "4640" band is gone, and the region contains only the *normal* 4640 NIII and 4686 HeII bands, then the "4640 stage" is at an end, and the nova has reached the true nebular stage, the last but one of its many kaleidoscopic patterns.

The [OIII] radiations become more prominent than those of hydrogen when the nova is about 5.5 magnitudes below maximum. This occurs a couple of months after maximum light in fast novae, and later in slow ones,—though not as much later as one might expect from the leisurely character of their earlier changes. The intensity of the [OIII] bands relative to those of hydrogen is, however, rather different from one nova to another. In one case, Nova Pictoris 1925, the [OIII] lines never surpassed those of hydrogen, but faded after they had nearly attained equality. In Nova Aquilae 1918 and Nova Lacertae 1936, on the other hand, the strongest line, λ 5007, was of the order of ten times as strong as Hβ a year or so after maximum. These differences, as well as those mentioned above for [NeIII], are probably due in large part to differences of abundance.

In the visual region, the [NII] band at λ 5755 continues to strengthen in the nebular stage, while permitted NII emissions fade away. The [OI] emissions also weaken; the auroral line, λ 5577, is the first to fade, and $\lambda\lambda$ 6300 and 6363 follow. The bright lines of FeII have long since become inconspicuous, and the spectrum as a whole bears a striking resmblance to that of a planetary nebula, save for the great width of the bright bands, as contrasted with the narrow lines of a normal planetary. The last strips of Plates II and III represent the nebular stage, soon after [OIII] has surpassed hydrogen.

The Nebular Shell

Six months after light maximum of Nova Aquilae 1918, Barnard found the star surrounded by a small nebulous disk which increased uniformly with time during many years afterward. Spectra taken in 1920, with the slit across the disk, and the central star held at the center of the slit (*i.e.*, not allowed to drift along the slit as is commonly done in taking stellar spectra), reveal the sources of different parts of the emission. Each bright band had the appearance of a fragmentary

ellipse. Clearly this was caused by an expanding shell of gas which was at least roughly spherical, but whose velocity of expansion was not precisely the same in all directions, and in which the distribution of material was by no means uniform. The broad band structures plainly did not originate in the central star or even near it. Most important of all, the width of each ellipse in the direction of dispersion was the same as that of the broad bright bands of the principal spectrum in the earlier stages, and individual maxima in the band structure could be referred definitely to particular parts of the nebulous disk,—that is, to specific knots of outward-rushing gas.

At the same time, the central star gave a spectrum that was purely continuous, save for a distinct *narrow* undisplaced knot of emission at λ 4686 HeII. During the next few years, similar knots developed at the positions of the hydrogen lines, and all of these narrow knots of the "post-nova stellar emission" were still present when a Michigan spectrogram was taken in 1942. However, the hydrogen knots were not seen at all until some time after the hydrogen emissions of the nebular shell had disappeared.

The emissions of the nebular shell were not photographed after 1922, for they had become too faint. This fading was of course due to the continued expansion and thinning of the shell, and the consequent reduction of its surface brightness as it moved away from its source of excitation,—the central star. The shell, however, was recorded on direct photographs by Baade in 1940,[10] and the velocity of expansion was sensibly constant over the interval of 22 years.

Another fine example of an expanding spherical shell is furnished by Nova Persei. The nebula about it is much brighter than that about Nova Aquilae, and it gives band patterns which are about two thirds of an ellipse, while the central star has emission bands of hydrogen and HeII several angstroms wide. In this case the hydrogen knots in the star spectrum are at the centers of the elliptical patterns due to the shell. There are, of course, no such knots at the centers of the ellipses of the nebular lines. In this case, as with Nova Aquilae, the width of the ellipses in the direction of dispersion is almost (if not quite) equal to the width observed in the emission bands of the principal spectrum many years earlier. Nova Persei may have ejected more matter than most other stars,[11] and its visible nebula has had a correspondingly long life.

The observations of both these novae prove that the visible expanding nebula was actually the same body of gas as that which produced the principal emission bands throughout the whole spectroscopic history from just after light maximum until the nebular stage. In other words,

[10] Reproduced in "Atoms, Stars and Nebulae," page 160, Aller and Goldberg.

[11] However, the calculations of C. and S. Gaposchkin do not show Nova Persei to have been particularly outstanding as regards mass of material ejected (*H.C.* 445.)

the history of the principal spectrum from its first emergence is the history of this expanding cloud of gas, which at last becomes large enough to subtend a measurable angle as viewed by observers on the earth. The elliptical patterns of the bright bands depend on the angular extent of the nebula, the velocity of expansion, and the dispersion employed. The angular diameter determines the diameter of the ellipse perpendicular to the direction of dispersion, while the velocity and dispersion together determine the extent of the ellipse along the spectrum.

The Post-Nova or Wolf-Rayet Stage

The fading away of the nebular spectrum of the expanding shell brings us to the last known stage,—that of the "post-nova stellar emission spectrum." It has already been indicated that this consists of a continuous spectrum with relatively narrow undisplaced emission knots of hydrogen and HeII. In some novae, HeI, CIII, and a few other bands have been found. Humason's work, referred to in the section on the pre-nova stage, has shown that such a spectrum is characteristic of a considerable percentage of former novae. The rest have pure continuous spectra with neither absorption nor emission lines.

The composition of this emission spectrum is so similar, in a general way, to that of some Wolf-Rayet stars that the name "Wolf-Rayet stage" has been used for many years to designate this last chapter of nova history. We might conjecture a subdivision into two parts: an early post-nova stage in which the bright lines are strong, and a later one in which they are absent. But this must remain a conjecture for the present, since the objects of Humason's list show no relation between "age" and intensity of bright lines relative to the continuum.

Mistaken ideas of earlier years were based on the tacit assumption that the nebular and stellar emissions came from a single source. The evidence of Nova Aquilae and Nova Persei is now conclusive in showing that there are two entirely distinct masses of matter involved. The older and incompletely observed novae left it still in doubt whether the narrow post-nova emissions were a separate feature, or merely resulted from a narrowing of the wide emissions of the earlier phases. The simultaneous existence of the wide bands due to the nebular shell, and the narrow bands in the star spectrum, is of course conclusive. Failure to observe the phenomenon in many more cases is surely due simply to the fact that the narrow emissions are completely enveloped and obscured by the wide ones, even after the latter have clearly developed the elliptical pattern. This is pretty surely the case in Nova Herculis at the present time.

Spectral Oscillations

Some novae,—especially slow ones,—instead of declining smoothly, are subject to strong secondary variations of light during the first six or seven magnitudes of their decline. If their fluctuations are artificially smoothed out, both as regards spectrum and magnitude, the

relation between stage of spectral development and magnitude difference from maximum is much the same as that for the stars which fade without such variations. Each oscillation of light carries with it an oscillation of the spectral characteristics. There seems to be no exception to the general rule that a brightening of the star is accompanied by a reversion of the spectrum to an "earlier" stage that had already been passed during the decline.

Oscillations of light during the first two magnitudes of the decline from maximum involve fluctuations between strong and weak diffuse enhanced spectrum at the minima and maxima of light respectively. An example of this was the early behavior of Nova Pictoris, which had three bright maxima of light.

When the fluctuations occur farther down the decline, they may be accompanied by changes from strong Orion and weak diffuse enhanced spectra to weak Orion and strong diffuse enhanced, as the star brightens to a secondary maximum. Nova Geminorum 1912 and v 356 Aquilae 1936 are fine examples of this behavior.

Still later, the nova may vary between the early nebular stage and the "4640" stage at the minima and maxima, respectively. Oscillations of this character occurred in Nova Persei 1901 and Nova Aquilae 1918.

The phenomena of these oscillations have been discussed in more detail elsewhere.[12]

Temperatures

All available information on energy distribution in the continuous spectrum, and on intensities of lines of various excitation potentials, indicates that the *lowest* "surface temperature" of the nova occurs at or about *maximum* light. As the star fades, the energy distribution in the continuum changes towards greater relative strength in the shorter wave-lengths, and both the absorption and emission spectra apparently respond by developing towards higher excitation. The fluctuations of light just described are accompanied by oscillations of both color and excitation temperatures, in the sense that the "star" is coolest at the maxima and hottest at the minima of light.

All of these changes are just the opposite of what we should expect to find, if the light variations were due to simple heating and cooling of the surface layers of a stable star. We must therefore exclude from consideration any theory that requires that the rise to maximum be due primarily to an increase of the intensity of radiation per unit area. In fact, we are simply driven to the conclusion that, since the nova rises to maximum light *in spite of* the fact that it is cooling, therefore the effective surface of the star must undergo a tremendous increase of area during the rise to maximum. This is the point of departure for an interpretation of the nova spectrum in terms of a physical-geometrical model, which will form the subject of an ensuing paper.

[12] McLaughlin, *Mich. Publ.*, **8**, 173-181, 1943.

Cambridge, Massachusetts, December 27, 1943.

Residential Mortgage Loans and Sunspot Numbers

By WALTER G. BOWERMAN

Doubtless most persons would say that if there is any connection between the frequency of sunspots and the amount of mortgage loans it is so remote as to be undiscoverable and so slight as to be negligible. However, the diagram in the following paper indicates a correlation so close as not to be easily accounted for as a matter of chance. If the relationship is only a coincidental one, it is certainly an unusually striking one. EDITOR.

In the May, 1943, number of the *Monthly Labor Review* (p. 939) there appears a tabulation of the total of mortgage loans by Savings and Loan Associations of the United States on residential building during each of the twenty years 1923-1942. Chart A shows these figures compared with the sunspot numbers (Wolfer). For the sixteen years 1923-1938 the correspondence is very close. Every movement in the one curve is paralleled by a similar movement in the other curve. The relationship is direct and not inverse. During 1939-1941 the relationship did not hold. A number of European countries were engaged in World War II from September 1, 1939. In fact, the invasion of Czechoslovakia started with the occupation of the Sudetenland after Munich (October 1, 1938), while the rest of that nation was taken over in March, 1939. But I do not know that those facts would in any way explain the break in the correspondence between these two curves. In 1942 the lines were again parallel.

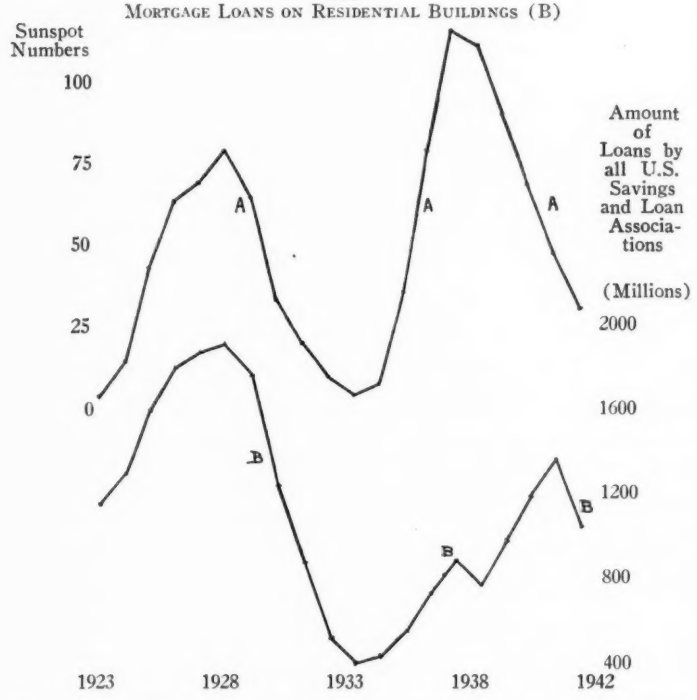
The figures themselves are reproduced in Table A. In each curve the peak was in 1928 and the lowest point in 1933, the memorable year in which all the banks in the United States were closed for a short, tense period. A second peak was reached in each curve in 1937. For the five years from the peak of 1928 to the low point in 1933 the one curve can be almost exactly superimposed on the other curve. This is indeed a remarkable fact. The rise and fall of the volume of these financial transactions is related to the impulse to establish a home for one's family, and the chart suggests that over a period of sixteen years these fluctuations have also been referable to certain powerful magnetic and electrical disturbances on the surface of the sun itself.

In his book "Sunspots and Their Effects" (1937) Dr. H. T. Stetson describes work done by Dr. Ernest W. Brown in 1900, which showed that the principal agent in causing sunspot disturbances is the revolution of the planet Jupiter about the sun. Modifications are caused by the gravitational pulls exerted particularly by Saturn, Mercury, and Venus, and perhaps even the Earth, but the most powerful influence is Jupiter. It intrigues one's fancy to reflect upon the beautiful mythology of the

ancient Greeks, which after 2,500 years receives this strange confirmation from the modern science, astrophysics. For more than 2,000 years prior to Galileo's invention of the telescope (1609) the Greeks taught that Jupiter was "the boss," who presided over all the other deities, and whose influence upon human life was most potent and significant. Thus the oath "By Jove" has come down the centuries as one to make men tremble. In reading Bulfinch's "Age of Fable" we must recognize the sheer Beauty in those brilliant inventions of the human mind, which we call Greek mythology. And now one is tempted to re-read those fascinating stories of gods and demi-gods to see wherein they may also have represented Truth.

CHART A

SUNSPOT NUMBERS (A)
AND
MORTGAGE LOANS ON RESIDENTIAL BUILDINGS (B)



These correlations were all positive. Using the data of Table A, the usual product-moment (X and Y) method gave .29 and the rank correlation method gave .34. Using the first differences of the figures in Table A, the product-moment method gave .57. It will be noted that the data of this problem are raw data and not refined indices. In

1934 Mata and Shaffner stated that in relating sunspots to business conditions it was the increase or decrease in the number of spots which showed the closest correspondence. This was in contrast to the conditions when world temperatures were studied, for the latter were closer to the total number of sunspots, rather than to their yearly variations. Reference to Chart A shows a clearer picture than can be given by a correlation ratio.

TABLE A

Year	Amount of Loans made by All Savings and Loan Assoc'ns. U.S. (millions)	Sunspot Numbers (Aver. No. per Day)
1923	$1187	5.8
1924	1315	16.7
1925	1620	44.3
1926	1824	63.9
1927	1895	69.0
1928	1932	77.8
1929	1791	65.0
1930	1262	34.0
1931	892	21.2
1932	542	11.1
1933	414	5.6
1934	448	8.7
1935	564	36.1
1936	755	77.1
1937	897	114.4
1938	798	109.5
1939	986	88.7
1940	1200	67.8
1941	1379	47.5
1942	1051	30.6

Using the data of Table A, omitting those of the last 4 years, the usual product-moment (X and Y) method gave .32 and the rank correlation method gave .46. Using the first differences of these figures in Table A, the product-moment method gave .89. This is a very high figure, when we remember that the data are not refined by any grading or by relating them to any standard. It is however in accordance with what would be expected from Chart A.

Many writers have investigated the cycles in building activity covering the period since the Civil War. Two of these are mentioned in the bibliography (items 4 and 5), and their papers contain extended references to numerous earlier studies in this field. One of them concluded, after an exhaustive mathematical analysis, that the chief causative factor in the construction of residences was a shortage of houses two years earlier. The amateur would have been inclined to believe that the main reason for building houses would be a shortage at the time of construction. This reminds one of (a) the alleged remark of a former President, now deceased, that when millions of people are involuntarily out of work, unemployment is extensive, (b) Professor Picard's observation, after a pioneer stratosphere ascension, that "the sky is blue," and (c) the thesis for the doctor of philosophy degree in which it was concluded after many exhaustive tests that "children of age eight to ten

years are ego-centric." As the *New York Times* commented, we are relieved to learn that this confirms the opinion held by parents for the last 12,000 years. With these examples before me, I have refrained from producing attenuated rationalizations of the facts shown in Chart A and Table A. Benjamin Franklin is reported to have said that when you have done something, you are not much good unless you can give six reasons why you did it. Yet in the present instance discretion may be the better part of valor.

In August, 1937, the magazine *Fortune* reviewed the subject of building cycles and found that 18 years was the usual length, and that this was longer than most business cycles. Professors Warren and Pearson stated in that article "The building cycle and the price level are so little known that most investors are whipped about by two forces concerning which they know little and over which they individually have no control. For it is difficult to get an education by experience in either the building cycle or the price level; major fluctuations are too infrequent." Unfortunately in their article, as in so many earlier papers on building cycles, all types of construction were combined—skyscrapers, factories, lofts, apartments, and private residences. I believe it may be significant that my Chart A includes only residential building.

During the twenty years covered in Chart A the population of the United States increased from 112 to 134 million. It may be contended that the amount of loans on residential buildings should be expressed in proportion to the numbers of the population. This has been done and the resulting curve has its highs and lows in the same years as Chart A. The only difference is that the fluctuations are less pronounced. If one were to extend the curve as far back as the Civil War some such modification would presumably be required.

When it comes to any *real* relationship between solar radiation and economic phenomena on the earth, most people still take a skeptical attitude. Although sunspots have been observed occasionally with the naked eye over many centuries, the telescope was not invented until 1609, and most of our more intimate knowledge of their activity has been acquired since 1900. An introductory study for such critics may be found in the paper by Drs. Garcia-Mata and Shaffner (item 6 in the bibliography), and a more extended treatment in Dr. Stetson's book (item 1). A number of America's most distinguished scientists have given the weight of their opinion to a belief in the reality of such a solar-terrestrial relationship. In the two references cited a review is made of certain hypotheses which have been offered to explain the mechanism by which solar radiation may influence economic conditions on the earth. It would be beyond the scope of the present paper to enter into those extended explanations.

I shall look forward in the years to come to observing the annual extensions of curve (A). Meanwhile I am pleased to share them with others, who may find in them at least an odd curiosity and perhaps

also some tentative indications of more fundamental and representative relationships.

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Teaching and Textbooks in Astronomy

By VICTOR GOEDICKE

In the course of teaching astronomy to Yale undergraduates, I have come to the conclusion that the existing textbooks are not ideally suited to the needs of college students. The unsuitability arises from the fact that all textbooks are written to serve simultaneously the student as a textbook and the astronomer as a reference book. These two purposes conflict with each other in many respects, and in most cases the astronomers have received the lion's share of the attention. I think that students deserve a textbook created solely for their needs.[1] The present article is an attempt to analyze these needs from the student's point of view, and to set down the specific points which, in my opinion, should be incorporated into such a textbook. My purpose in publishing it is to stimulate discussion among teacher of astronomy about the issues raised, and to clarify my own ideas, with the possible ultimate objective of incorporating them into a textbook.

To remove any ambiguity, let me further exclude the interests of students who intend to become astronomers; my textbook would be created solely for those liberal arts students who intend to take no further courses in astronomy. Those few students who later become astronomers will recover quickly from any ill effects resulting from the use of such a textbook.

I. SEQUENCE OF PRESENTATION. In my classes, the students have invariably found the sections on the physical properties and the motions of the stars most difficult. The difficulty appears to arise from a feeling that these sections of the book consist of a large collection of unrelated facts, with no clearly apparent unifying pattern. Insofar as this

[1] Professor Duncan's "Essentials of Astronomy" deserves recognition as a book of this type, but it is too brief for the use here being considered.

feeling is justified, it constitutes an overwhelming barrier to the student's progress. A student taking fifteen hours of lectures per week is receiving facts at (or beyond) his capacity to assimilate them, and if the facts in any course cannot be fitted into a logical pattern the game is lost.

My experience in trying to meet this problem has lead me to the following conclusions, the third of which contains my primary thesis:

1. In planning the order of presentation, the fact that topics are investigated together by astronomers is not a sufficient reason for discussing them together. For the student, the instrumental association of different types of research is accidental.

2. Likewise, a historical sequence of development does not give the student an adequate feeling of relatedness.

3. It is not good practice to introduce independent descriptive material whose primary significance will appear later; it is much better to postpone the topic until it can be introduced as part of the solution to a larger problem which is already before the student. Thus it is bad practice to present a section on "The Spectral Sequence" as independent descriptive material from which physical data will later be derived, and it is good practice to present a section on "Stellar Temperatures," in which the spectral sequence is introduced as one of several lines of research leading to temperatures. The fact that the spectral classification leads also to other information is not sufficient reason for making it a separate unit.

In defense of these somewhat arbitrary statements, I appeal to the reader's classroom experience. Every teacher knows that one of the best ways to maintain unity of thought (and to hold the interest of the students!) is to begin by raising a question, and then to develop the lines of thought which enable us to answer that question. Until the complete answer to the question has been assembled, no by-paths of thought should be followed and no new questions should be raised. Furthermore, the question itself must meet specific requirements:

1. It must make an immediate appeal to the curiosity of the student about the physical world. Its significance must be apparent from the start, and it must therefore be a question which can be stated in terms with which the student is already familiar.

2. It must have a specific answer which the student will immediately recognize. (I do not of course rule out the specific answer "Astronomers do not know.")

These classroom observations can be directly applied to the planning of a textbook: The material should be so arranged that each chapter and each sub-chapter develops an answer to a specific question, which, furthermore, meets the two criteria given above. For instance, if we test the hypothetical headings given earlier by stating them as questions,

we see that "How Hot are the Stars?" meets the criteria while "What is the Spectral Sequence?" does not.

I have for several years followed an order of presentation based upon this line of thought, and if I were writing a textbook I believe that I would adopt it. In addition to the smaller-scale rearrangement of material in accordance with the foregoing discussion, the larger units of astronomical knowledge are arranged in a way which, I believe, make the student's path more straightforward. The chapters on the stars are divided into two large sections, the first dealing solely with the intrinsic physical properties of the various types of stars, and the second dealing solely with the spatial arrangements and motions of the stars. In the section on the physical properties of the stars, the physical properties of ordinary stars are completely described before variables are discussed; in this way the peculiar physical properties of the variables have more significance than they would otherwise have. Some sections of my outline are reproduced below. They are taken from my notes in which the material for a one year course is divided into six parts, containing altogether eighteen chapters. In writing these chapters, no attempt would be made to make them of equal length, as this would introduce an artificial division of material which would defeat my purpose.

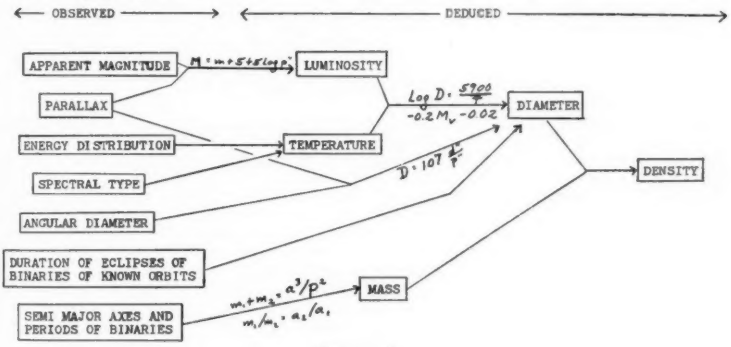

FIGURE 1
FUNDAMENTAL DETERMINATIONS OF PHYSICAL PROPERTIES

PART FOUR. THE STARS AND NEBULAE

CHAPTER IX. FUNDAMENTAL DETERMINATIONS OF PHYSICAL PROPERTIES OF STARS.

This chapter is built around the diagram in Figure 1, which would be given a prominent place in the book.

Distances: Methods of obtaining and studying parallax plates; distance parallax formula.

Luminosities: Apparent visual magnitude scale; methods of measuring magnitudes; absolute magnitudes and their derivation.

Temperatures: Spectrophotometric and spectrobolometric techniques and color temperatures. Inadequacy of method for hottest stars, and deduction of far ultra-violet intensities through ionization effects for these cases. Methods of

stellar spectroscopy and the spectral sequence; excitation and ionization temperatures.

Radii: Derivation of the luminosity-temperature formula for radii, assuming black-body radiation. Introduction of spectroscopic binaries and principle of obtaining radii from eclipsing stars of known orbits. Interferometer and its results. Agreement of latter two with first justifies black body assumptions and general applicability of first.

Masses: Statement of Kepler's law, and its derivation for circular orbits from the formulae for centrifugal force and the law of gravity. Theory of visual binaries. The orbits of representative binaries and computation of their masses.

Density: Computation from mass and radius. Discussion of confirmatory evidence from Einstein shift and from eclipsing binaries.

Chemical Composition: Uniformity assumed in temperature derivation from spectral type; evidence for uniformity assembled; deviations from uniformity in O stars and in R and N stars; table of percentage composition of surface of normal stars.

CHAPTER X. RELATIONS BETWEEN THE PHYSICAL PROPERTIES OF THE STARS.

THE SPECTRUM-LUMINOSITY RELATION

The Mass-Luminosity Law: This would be here treated as an empirical relation, with a statement that its theoretical derivation is to be discussed later.

Spectroscopic Absolute Magnitudes: This topic should, in strict logic, be divided between chapters 9 and 10, since it combines the fundamental determination of a physical property—atmosphere density—with a correlation between physical properties—atmospheric density and luminosity. I think that strict logic can well be foregone here.

Summary: Collection of results in a table of the properties of representative stars, and in a figure combining all of the correlations. Statement of the place of these correlations in astronomy, both as a means to further information about specific stars, and as a means to our understanding of the structure and evolution of the stars.

CHAPTER XI. STELLAR STRUCTURE

Internal Constitution: Description of internal physical properties: Density, temperature, pressure, radiation density and pressure, degree of ionization, rate of diffusion, etc. Qualitative description of methods of research. Principal uncertainties.

Energy Generation: Old methods considered and rejected. Mass-energy relation and its history; the cyclotron and nuclear physics; the carbon cycle and its application to the main sequence; possible other sources for the giant stars.

Stellar Atmospheres: Stratification observed in the sun, Zeta Aurigae, and VV Cephei. Pressures in atmospheres. Curve of growth; turbulence.

Stars of Unusual Interest: Beta Lyrae, Epsilon Aurigae, and others.

CHAPTER XII. VARIABLE STARS

CLASSIFICATION OF VARIABLES.

Cepheids: This section could, I believe, profitably include a qualitative description of the progressive wave and the convective zone theories of Cepheid variability, since the chapter on stellar structure has preceded this one.

Irregular Variables.

Novae and Supernovae.

CHAPTER XIII. NEBULAE AND INTERSTELLAR MATTER

Planetary Nebulae: Descriptive.

Diffuse Nebulae: Descriptive.

Physical Properties of the Nebulae: The spectra of nebulae and the deduction of the pressures, temperatures, densities, and states of ionization of the nebulosity and the physical properties of the associated stars.

Interstellar Matter: Absorption lines in stars; emission lines from the sky; sizes of the particles and ratio of metallic to non-metallic particles; chemical composition of the gases; mechanics of interstellar matter.

PART FIVE. ARRANGEMENT AND MOTIONS OF THE STARS

CHAPTER XV. LOCAL MOTIONS OF THE STARS.

The Solar Motion: The solar motion from radial velocities and proper motions; random motions in space of the neighboring stars.
Double Stars: Systematic treatment of material not already covered; statistics of binaries.
Common Motion Groups.

CHAPTER XVI. STAR CLUSTERS

Appearance of Clusters.
Distances and Dimensions.
Spectral Types of Cluster Stars.

CHAPTER XVII. GALACTIC STRUCTURE

Star Counts: Methods of counts; tables of results; preliminary computation of galactic dimensions.
Distribution of Cepheids and other stars of known luminosity.
Distribution of Globular Clusters.
Interstellar Absorption: Methods of measurement; correction of preliminary dimensions.
Galactic Rotation: Radial velocities. Proper motions.

PART SIX. THE METAGALACTIC SYSTEM

CHAPTER XVIII. THE GALAXIES

Distances and Dimensions: History of theories of the spirals; their spectra; Cepheids in nearby spirals; novae, etc.
Types of Galaxies: Hubble's classification; description and illustration.
Structure of the Galaxies: Mass distribution from radial velocities. Contents of galaxies: clusters, gaseous nebulae, etc.; peculiar distributions of various objects in them.

CHAPTER XIX. DISTRIBUTION AND MOTIONS OF THE GALAXIES

Distances of Remote Galaxies: The Harvard classification. Angular diameter or apparent luminosity of galaxies whose actual diameters or luminosity is deduced from their galactic type. Angular diameter or apparent luminosity of "average" galaxy.
Groups of Galaxies: The local group; the Virgo group; others.
Motions of the Galaxies: Proper motions not observable; radial velocities and their correlation with distance; the alternative explanations; the "age" of the universe.
The Universe: Gravitational and luminosity discussions of a finite or infinite universe; relativity and the expanding universe.

This concludes the outline, and the first topic of this article.

II. ANALYSIS VERSUS CONCLUSIONS. A textbook must make a compromise in emphasis between presentation of facts and presentation of the logical steps leading to them. Probably the average student remembers only a small fraction of either for very long. However, *the primary value of the course to him lies not in what it leaves in his memory but in the part it plays in his intellectual development while he is studying it,* and from this point of view there is more value in following the astronomer's reasoning than in memorizing his conclusions. I believe that a textbook should emphasize the means of arriving at solutions of problems in all cases, unless this takes the student hopelessly beyond his depth. The course is made more interesting as well as more valuable to the student if he participates in the battle for facts instead of only receiving the end product. (I am reminded of the analogy, not original

with me, with the relative desirability of participating in a fox hunt and of being handed—a dead fox!) I believe that formulae should be explained qualitatively (and if feasible also derived rigorously) and then immediately *applied*. Furthermore, they should be applied in the most direct way possible, mathematical refinements being postponed until the student sees the principles clearly. For instance, in treating the formula for the radius of a star as a function of its temperature and absolute magnitude, I have found it profitable to begin by selecting a given star, and computing, from its temperature, its energy output per square centimeter, then its entire surface output by comparing its absolute magnitude with the sun's, then its area by dividing these two, and finally its radius. This procedure is then generalized and condensed into the familiar formula. To simplify the procedure first and then work out an example from the formula would leave many students with a less clear understanding of the principles involved. Incidentally, after following through the lengthy procedure suggested here, the students may have a better appreciation of the logical compactness achieved by the formula.

The objective of student participation should be carried further: many tables of primitive observations should be included in the book, and an appendix should contain a set of three-place logarithms and instructions for using them. The students could then, for instance, compute the masses of a dozen binaries and "discover" the mass-luminosity law. I recall a statement—at least as fair as most analogies—that teaching a science without asking the students to perform the operations is like teaching a boy carpentering by conducting him through a museum of carpentering tools!

III. The Language of Astronomy. That the terminology which astronomers use in their work should be taught to students who intend to become astronomers goes without saying. But I am proposing that a book be written primarily for that 95% of the students who do not intend to continue their studies beyond their single year of astronomy. No special terminology should be taught to such students unless it has an immediate purpose in facilitating a discussion. No special mathematical symbolism should be introduced if an equally good symbolism already exists in the student's previous training. A specific example is our absolute magnitude scale. We are so familiar with it that we forget that it is an awkward scheme from the point of view of students. To ask students to familiarize themselves with it is to place a completely pointless obstacle in their paths. We should use instead the more natural notation of luminosities, with perhaps an explanation of absolute magnitudes in a footnote.

To pick a few other examples at random, I should place in the same category the words "opposition," "conjunction," "quadrature," and "syzygy," which are customarily defined and then laid on the shelf.

Definitions of the ecliptic and galactic systems of coordinates fall in the same category, except that the latter might be justified if introduced at the point *where it is specifically* needed rather than as part of an independent topic on coordinates.

IV. The Scope of a Textbook. There are several points of contact between astronomy and other fields—for example, the age of the earth—and at these points most writers display a natural reluctance to present themselves as authorities about topics not strictly in their own fields. But the books should be written to meet the needs of the students, and not to conform to the conventions of scientific propriety. From the student's point of view the only consideration is that excessive duplication from course to course would waste his time, and the danger of this is not great. To follow the example of the age of the earth, the number of students who take both geology and astronomy is small; liberal arts students not "majoring" in a science are usually required to study only one science, and do not often overshoot the mark. I think that it would be entirely proper for a textbook in astronomy to include fairly complete discussions of relevant related topics.

About other such points of contact I am more in doubt. In discussing the possibilities of life on planets other than our own (a topic of importance to the student, and, I think, a legitimate one for discussion in a course in astronomy), most books go no further than to state that life as we know it appears to be impossible on other planets. But the student should certainly be told that in view of the fact that forms of life adapt themselves, within limits, to their environments the phrase "life as we know it" is too restrictive, and the possibility exists that a slow change of conditions on Mars to the present ones may have enforced a different line of development from primitive forms of life, leading to forms (totally unlike our own) which still exist. The student cannot intelligently evaluate these possibilities unless he knows something of the mechanism of organic evolution, and I have sometimes included some discussion of this in my lectures. From the student's point of view it properly belongs in the course, but whether I should dare to violate convention by including it in a textbook I do not know.

Before leaving this point, I should like to remark that students often find college education an extremely disjointed affair, with each subject insulated from all others. If he achieves a sense of the unity of human knowledge he does so in spite of this rigid delimitation of course material. I believe that the interrelations between subjects should be emphasized rather than depressed.

Perhaps we can find an example in the unadorned statement in textbooks to the effect that astronomy has had a profound effect on human thought. Where is the student to learn about this effect, if not in a course in astronomy? The liberal arts students are not studying to become professional astronomers, and their interests are legitimately

broad enough to include the question of what part astronomy plays in human affairs. Here again I am not sure how far the textbook should go, as distinguished from the lectures.

V. A COMMENT ON NAMES. Existing books vary widely in the number of names of astronomers included in the text, from several hundred at one extreme to none at all at the other.* An extensive inclusion of names makes the book useful to astronomers, but, I repeat, students deserve a book written solely for them. For a student, the inclusion of a name with which he is not familiar and which he will probably never see again is nothing but an impediment to his reading, and an overgenerous inclusion of names turns the book into an obstacle course. I believe that only names already familiar to the student should be included, plus perhaps a dozen, living and dead, whose contribution is so great that the student's knowledge of astronomy would be markedly incomplete without them. Such men should then merit a few lines or a brief paragraph of personal and scientific history, and perhaps a picture, so that later references to them would have some substance.

In the above notes there are many implicit criticisms of existing books. Let me say that in the course of using these books, both as a student and as a teacher, I have formed a high regard for their worth.

*For instance, Strömgren and Strömgren, "Lehrbuch der Astronomie."

YALE UNIVERSITY OBSERVATORY, NEW HAVEN, CONNECTICUT, JUNE 2, 1943.

Certain Effects of Rapid Stellar Rotation

By RALPH B. BALDWIN

It seems well established that rapid rotation is a frequent characteristic of early-type stars. Miss Westgate[1] and Struve[2,3] have made many studies which indicated this property clearly. However, it has not been generally recognized that if a star is spinning rapidly certain of its properties—brightness, temperature, and spectral class—are modified. The last of these is changed in a manner which should be observable.

Rapid spinning distorts a star; it becomes an oblate spheroid. The degree of oblateness depends on the ratio of centrifugal force to gravity. This may be computed by the well-known formula:

$$\phi = 3\pi/G\rho P^2, \qquad (1)$$

where G is the gravitational constant, ρ is the mean density, and P is the length of one complete rotation.

To determine P and ρ we shall postulate a star with a temperature of 19,000° K, a mass of 10 $\odot$, and an absolute magnitude of —2.5,

[1] *Ap. J.*, **77**, 141, 1933.
[2] *Ap. J.*, **69**, 173, 1929.
[3] *Ap. J.*, **73**, 99, 1931.

whence its radius is 6.2 ⊙ and ρ is 0.06. These values may be considered as typical of B stars in general.

If we assume that the star is rotating so rapidly that ϕ, the ratio of centrifugal force to gravity, is 2/5, we may solve for the period, 7.8×10^4 seconds, and then for the equatorial velocity, 338 km/sec.

The degree of oblateness, ϵ, depends on the quantity ϕ, but also on the distribution of matter within the rotating body. For a solid body with the mass concentrated near the center, $\epsilon = \frac{1}{2}\phi$. This will be assumed to hold in the case of a star. Hence

$$\epsilon = \tfrac{1}{2}\phi = a - b/a = 1/5, \tag{2}$$

where a is the semi-major, or equatorial radius and b is the semi-minor, or polar radius of the distorted star. Therefore

$$a = 5b/4. \tag{3}$$

This star, if viewed from the polar direction presents a circular cross section which is 1.25 times the area of the elliptical cross section of the star as seen from the equatorial plane.

Accurate observations of eclipsing binaries show that "gravity darkening" is an effect which must be taken into account wherever stars are appreciably deformed. The surface brightness is proportional to the surface gravity.

For the case of a rapidly rotating star we may assume for simplicity and ease of calculation that

$$E \sim g \sim 1/r^2 \sim T^4, \tag{4}$$

where E is the surface brightness, g the surface gravity, r the radius to the point in question on the star's photosphere, and T is the temperature.

The variations in $1/r^2$ are known from the postulated conditions and therefore the distribution in brightness and temperature may be computed; both quantities increase toward the poles.

Table 1 gives the values of E and T for 10° steps in astrocentric latitude. The temperature at the pole was arbitrarily chosen to be 20,000° K.

TABLE 1

L	E	T
0°	0.639	17,880° K
10	.650	17,960
20	.682	18,170
30	.718	18,420
40	.772	18,750
50	.850	19,200
60	.910	19,530
70	.958	19,780
80	.989	19,940
90°	1.000	20,000° K

When this energy distribution is mechanically integrated over the projected photosphere of the star as seen from the polar direction the combined radiations have a distribution of intensity corresponding approximately to 18,880° K on the assumption of a uniform disk, *i.e.*, without limb darkening. The same star, if viewed from the equatorial

plane would appear to have a color temperature of 18,380° K or 500° less than on the previous assumption.

Consequently the brightness of the star varies both because of geometrical reasons and because the apparent temperature is a function of the angle between the line of sight and the equatorial plane. The geometrical factor is 1.25, that due to the temperature difference is 1.12.

Thus, the rotating star would appear 1.40 times as bright bolometrically if seen along the axis as if viewed from the equatorial plane. This corresponds to 0.36 magnitude (bolometric) or 0.28 magnitude (visual).

The dependence of spectral type on temperature is not well determined for the early type stars. We shall assume that a B0 star has a temperature of 23,000° K, an A0 star one of 14,000° K, and an A5 star one of 11,500° K. With these values defining a curve we may read off spectral classes corresponding to each temperature. The spectral type for 18,880° K is B3.1, that for 18,380° K is B3.7, a difference of 0.6 step.

This difference is probably too small to be significant in individual cases, but statistically the stars which are seen from the polar direction should be classified slightly earlier than those which are seen from the equatorial direction.

Studies of the sun and eclipsing binaries have shown that limb darkening is a factor to be taken into account in all photometric work. We shall assume a law of darkening

$$J = J_o (1 - u + u \cos \theta) \qquad (5)$$

where J equals the total radiation at a point defined by the angle θ, the angle of foreshortening. The constant, u, has been assumed to be 0.5 for computational purposes. J_o is the intensity of radiation at the star's apparent center.

With this added condition a similar mechanical integration was performed and the apparent temperatures as seen from the polar and equatorial directions become 17,940° K and 17,340° K, respectively, which give spectral classes of B4.2 and B4.9.

Because of the limb darkening the temperature difference has been increased only from 500° to 600° and the spectral class difference from 0.6 to 0.7, although the absolute values have been altered. The limb-darkened star as seen from the polar direction is 1.43 times as bright as when viewed at right angles to the axis. This may be compared with 1.40 determined similarly without limb darkening.

The effects under discussion are thus essentially unaffected observationally by limb darkening. Since very little is to be gained in accuracy by its inclusion, and since the computation becomes more involved for the equatorial view of a rotating, limb-darkened star, it has not been carried out except for the single case.

The same procedure may be followed for other rotational speeds and other degrees of oblateness (uniform disks). Table 2 summarizes the results.

TABLE 2

V	ϕ	ϵ	P	A	B	C	D	E	F	G	H
0	0	0	20,000	20,000	20,000	20,000	B2.1	B2.1	1.00	1.00	1.00
160	1/5	1/10	20,000	19,460	19,210	18,970	B2.6	B2.8	1.11	1.05	1.17
320	2/5	1/5	20,000	18,880	18,380	17,880	B3.1	B3.1	1.25	1.12	1.40
480	9/10	9/20	20,000	17,270	16,050	14,830	B5.0	B6.8	1.82	1.34	2.44

The column headed V, gives the equatorial velocity of rotation of the specified star in kilometers per second, ϕ is the ratio of centrifugal force to gravity, ϵ is the oblateness, P is the assumed temperature at the poles in degrees Kelvin, A is the apparent temperature of the star from the polar direction, B is the apparent temperature of the star from the equatorial direction, C is the computed temperature at the equator, D is the spectral class as seen from the polar direction, E is the spectral class as seen from the equatorial direction, F is the area of the star as seen from the axis direction relative to the area seen from right angles to the axis, G is the relative brightness, because of different temperatures, of unit average areas of the star as seen from the two directions, and H is the total effect in brightness, geometrical and thermal combined.

Thus theoretically the brightness, temperature, and spectral class of a rapidly rotating star are functions of the angle between the line of sight and the star's equator. In practice, however, the small temperature difference postulated would not be observable. Statistically the spectral class should vary as suggested, *i.e.*, the Bn and Bne stars should average later than the Bs and Bse stars.

Miss Westgate[1] and Struve[2,3] have shown that the B stars have n and s characteristics mainly because of their rotation and orientation. A star is classified as Bn or Bne because it is seen from nearly the equatorial direction and because its lines are broadened by axial rotation.

The actual distribution of equatorial velocities of rotation is unknown, hence we cannot predict exactly what differences in spectral class to expect. However, certain stars are observed to rotate with speeds of the order of 400 km/sec, and since the statistics of random distribution of axis directions give a greater probability that the line of sight lies nearer the stellar equator than the axis, a mean apparent rotational velocity difference of about 240 km/sec between the broad and sharp line B stars does not seem excessive. This corresponds to a difference in spectral class of about 0.4 or 0.5 step. This should be observable.

The following Table 3 suggests that the expected differences in spectral class actually are found, but it must be borne in mind that systematic errors may affect the classifications. The data are from the Washburn list by Stebbins, Huffer, and Whitford.[4] This catalog was chosen because it gives individual photoelectric colors.

Strangely enough, this statistical difference in spectral class is the only one of these effects which can be detected observationally, although

[4] *Ap. J.*, **91**, 20, 1940.

the others must exist.

The difference in magnitude for a given B star as seen from the two directions is about 0.19 magnitude (visual) while the difference in absolute magnitude for a spectral class difference of 0.4 step is 0.17 magnitude in the same direction and thus the effects cancel out and no magnitude difference between the Bs and Bn stars should be found. Actually Wilson[5] finds them to be of essentially the same brightness.

TABLE 3

DISTRIBUTION OF B-STAR CLASSIFICATIONS

Class	Bss	Bs	Bn	Bnn	Bse	Bne
B0	1	5	9	2	2	22
B1		11	6		1	4
B2	1	29	15	1	2	22
B3		38	35	3	1	42
B4			4			3
B5		18	48	4		16
B6		1	1			1
B7		6	7			
B8		6	8	2		1
B9		2	5			
	2	116	138	12	6	111
Aver.	B1.0	B3.34	B4.07	B3.92	B1.33e	B2.52e
		B3.30	B4.05			

NOTE: There is one other effect which has not been taken into account in this discussion. That is the change of ionization with a change in surface gravity. Off hand it would seem that a lowered equatorial surface gravity would lead to a lower electron pressure and hence to a higher degree of ionization than would be anticipated from the temperature condition only. It is possible that this is not the case. It must be remembered that the photosphere of a star is not a surface in the true sense. It is merely the region within a star at which the layers become opaque, when viewed from a specific direction. Because of the lower temperature at the equatorial photosphere the electron pressure would be less there than at any other photospheric region. But, however, the density gradient changes more slowly above the equator than above the poles. Hence a lower photospheric electron pressure at the equator does not necessarily mean a lower average electron pressure throughout the reversing layer.

It is seen that there exists a change of ionization over the surface of a rotating star due to changes in temperature. A second effect due to changes in electron pressure must also exist, but its magnitude and sign at present are unknown. It may or may not be sufficiently large to alter certain conclusions in this paper drawn from the temperature effect. Therefore results of changes in ionization because of pressure variations are not taken into consideration here.

From the Washburn list 31 Bs and 48 Bn absorption line stars have average color excesses of +0.010 and +0.009, respectively, apparently a space reddening effect only. Stars within 15° of the galactic equator were neglected in forming the above averages. The color excesses of Be stars are likewise inconclusive.

Color excess determinations are dependent on spectral class and if the spectral class of a particular star is a function of the inclination of its axis to the line of sight, the effects cancel out and both Bs and Bn stars will have the same colors for each spectral subdivision.

[5] *Ap. J.*, **94**, 12, 1941.

These paragraphs are not intended as explanations of obvious observational effects. They do, however, serve to illustrate by means of rough and approximate calculations some of the more subtle points which must be appreciated in order to establish a truer picture of the intricate mechanism we call a star.

DEARBORN OBSERVATORY,* NORTHWESTERN UNIVERSITY, EVANSTON, ILLINOIS, JUNE 29, 1943.

*The writer is on leave to the Office of Scientific Research and Development, Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland.

Rare Dates for Easter

By GEORGE W. WALKER

Apropos to the coming of Easter on its latest possible Gregorian date, April 25, in 1943, Alexander Pogo, of the Carnegie Institution of Washington, contributed an article to the May issue of POPULAR ASTRONOMY* which deserves to be carefully studied by all who are interested in Easter or in our complicated Gregorian calendar.

One paragraph of this excellent article seems to call for further consideration, and, possibly, correction. The author declares that "March 24 is the most unusual Gregorian Easter date"; and gives a table of early and late Easter dates covering eight centuries, which seems to bear this out. However, a more extended survey, or a study of general principles, will show that March 24 has no general claim to the distinction of being the most unusual Gregorian Easter date. It just happens to be the most unusual Easter date within the limited period covered by the given table.

A more extended table of early and late Easter dates is given herewith, which is carried out far enough to show more of the long-time trends.

TABLE I

EARLY AND LATE EASTER DATES THROUGH A PERIOD OF ABOUT 3000 YEARS

(Computed according to the rules adopted in the Gregorian calendar reform of 1582)

EASTER SUNDAY ON														
Mar. 22nd	March 23rd			March 24th			April 23rd			April 24th			Apr. 25th	
PASCHAL FULL MOON ON														
Sat. Mar. 21st	Fri. Mar. 21st	Sat. Mar. 22nd		Thu. Mar. 21st	Fri. Mar. 22nd	Sat. Mar. 23rd	Sun. Apr. 16th	Mon. Apr. 17th	Tue. Apr. 18th	Sun. Apr. 17th	Mon. Apr. 18th		Sun. Apr. 18th	
(1503) 1598	(1541)				(1568)		(1544 1533)						(1571)	
1693	1636								1628	1639			1666	
1761	1704	1788		1799						1707	1791		1734	
1818	1856	1845							1848	1859			1886	
		1913			1940		1916	1905					1943	

*"Uncommon Easter Dates" by Alexander Pogo, POPULAR ASTRONOMY, **51**, 254.

Mar. 22nd	March 23rd		March 24th			April 23rd			April 24th		Apr. 25th
Sat. Mar. 21st	Fri. Mar. 21st	Sat. Mar. 22nd	Thu. Mar. 21st	Fri. Mar. 22nd	Sat. Mar. 23rd	Sun. Apr. 16th	Mon. Apr. 17th	Tue. Apr. 18th	Sun. Apr. 17th	Mon. Apr. 18th	Sun. Apr. 18th
		2008				2079		2000	2011	2095	2038
		2160						2152	2163		2190
2285	2228							2220	2231		2258
2353		2380	2391							2383	2326
2437			2475						2478	2467	2410
2505		2532	2543						2603	2535	2573
		2600		2695		2671			2698	2687	2630
		2752						2744	2755		2782
				2847		2823			2850	2839	2877
2972			2915		2999		2975		2918	2907	2945
3029											3002
			3067						3070	3059	3097
		3124				3195		3116	3127		3154
				3219		3290	3279		3222	3211	3249
3401				3371		3347			3374	3363	3306
3496			3439			3415	3499		3442	3431	3469
3564			3507	3591			3567		3510	3594	3537
3648			3686		3675	3662	3651		3689	3678	3621
3716			3754	3743			3719		3757	3746	3784
				3811					3814	3803	3841
					3895	3882	3871			3898	
				3963		3939			3966	3955	3993
				4058	4047	4034	4023		4061	4050	4088
	4183		4126		4115	4102	4186	4175	4129	4118	4156
	4251		4289	4278		4197	4254	4243	4292	4281	4224
4308	4403		4346	4335			4311	4395	4349	4338	4376
	4498	4487	4441	4430			4406	4490	4444	4433	
								4547	4501		4528
		4555		4593	4582	4569	4558		4596	4585	
				4650	4639	4626	4615	4699	4653	4642	4680
5299											

A complete table of Easter dates could be constructed for any period of time on the principle of the incomplete table given here. It would have a total of 203 columns, each representing a given day of the week and a given date for the Paschal (full) moon. These columns would be grouped so that one or more adjacent columns would together give all the years in which Easter comes on a certain date; with a maximum of seven columns, for any Easter date between March 28 and April 19, inclusive. Only the six columns at the left edge of the complete table and the six columns at the right edge are given here.

If the present accepted Gregorian rule is extended indefinitely into the future, then, to a first approximation, the entries will appear with equal frequency, in the long run, in all the columns except those giving the date of the Paschal full moon as April 17 or April 18. Entries in these columns are about half again as frequent as in the others. If the table were extended indefinitely, all ordinary columns would average about one entry in every 210 years. A column making the date for the Paschal full moon April 17 would average about one entry in every 148 years (more accurately, 9 entries in every 1330 years). A column making the date for the Paschal full moon April 18 would average one

entry in every 133 years.

Assuming these long-time averages, we find that the most unusual Gregorian Easter date is definitely March 22, averaging one year in every 210. The second place goes definitely to April 25, averaging one year in every 133. The third place goes definitely to March 23, averaging one year in every 105. March 24, acclaimed by Dr. Pogo as the most unusual date, is tied with April 24 for fourth place, averaging one year in every 70. Easter on either of these two dates is, on this reckoning, just three times as likely in a year chosen at random as Easter on March 22.

A slight correction will have to be made to the above in view of the fact that in our present Gregorian calendar a given date will not come with equal frequency on the different days of the week. For example, in any period of 400 years, March 21 comes on Sunday or Tuesday 56 times each; on Thursday or Friday, 57 times each; and on Monday, Wednesday, or Saturday, 58 times each. This consideration improves by about 2% the relative frequency of Easter on March 22, as compared with the frequency of Easter on March 23 or 24.

In any case, the current rarity of Easter on March 24 is definitely not a long-time trend. In fact, within the thousand years following the period which Dr. Pogo shows in his table, Easter comes on that date about once each century, and about twice each century during the thousand years next after that. This helps to bring its total average up to its norm.

The extended table given herewith shows some other freaks of distribution, besides the comparative rarity of Easter on March 24 during this present period. Among the longer gaps for a given date, we may note the following: March 22 and 23 both show gaps of 372 years; March 24 and April 23 show gaps of 451 years; March 22 shows two intervals of 467 years, one of 592 years, and one of 991 years; and March 23 has one very long gap of 1059 years, following the year 3124, during which there isn't a single occurrence of Easter on that date. If the table were extended farther, longer gaps might be found.*

The table goes far enough to show plainly that March 22 and March 23 are really rare dates for Easter. Each of these dates has an interval of nearly or quite 1500 years during which there is just one occurrence of Easter on the given date.

These vagaries suggest how great would be the advantage of simplification if any of the recent proposals of calendar reform should be adopted, fixing the date of Easter according to some simple rule. If that change is made soon, this entire article will have antiquarian value only.

The author has made a complete calculation of the total number of

*Dr. Morgan Brooks, Professor of Electrical Engineering, Emeritus, of the University of Illinois, has called the author's attention to an interval of 1365 years, following the year 5120, in the list of Easters on April 25.

occurrences of Easter on the different possible dates, in the long cycle of 5,700,000 years, which is the cycle necessary, under the Gregorian rules for the calculation of Easter, to bring all the conditions determining the date of Easter around again to their starting-points. Table II given herewith shows exactly the comparative frequency of Easter on different dates, and the average interval on each date, in years. A comparison with the intervals given earlier in this article will show that the "first approximations" there used were, in general, safe guides.

TABLE II

LONG RANGE FREQUENCY OF EASTER DATES

Date of Easter	Number of Occurrences	Percentage	Average Interval
March 22	27550	0.4833	206 26/29
March 23	54150	0.95	105 5/19
March 24	81225	1.425	70 10/57
March 25	110200	1.933	47 21/29
March 26	133000	2.33	42 6/7
March 27	165300	2.9	34 14/29
Note*	186200	3.267	30 30/49
Note**	189525	3.325	30 10/133
Note***	192850	3.3833	29 133/203
April 18	197400	3.463+	28 188/329
April 19	220400	3.867	25 25/29
April 20	189525	3.325	30 10/133
April 21	162450	2.85	35 5/57
April 22	137750	2.4167	41 11/29
April 23	106400	1.867	53 4/7
April 24	82650	1.45	68 28/29
April 25	42000	0.737—	135 5/7
	5700000	100.	

*March 28, April 2, 4, 9, 11, and 16.
**March 30 and 31, April 6, 7, 13, and 14 (also 20).
***March 29, April 1, 3, 5, 8, 10, 12, 15, and 17.

The Planets in April, 1944

By WILLIAM A. CALDER

NOTE: Greenwich Civil Time is used unless otherwise stated. To obtain Eastern War Time, subtract 4 hours; Central War Time, 5 hours, etc. The information is taken from the *American Ephemeris and Nautical Almanac*.

Sun. During the month of April, the sun's position changes from $0^h\,41^m$, $+4°\,25'$ (in Pisces) to $2^h\,32^m$, $+14°\,58'$ (in Aries). On April 15, the equation of time is zero, and sundials will give mean time correctly (if one allows for his position in the time belt and also adds an hour to change to War Time).

Moon. The earth's satellite will be farthest away on April 4 at 18^h. Its phases are:

	d	h	m
Full Moon	April 8	17	22
Last Quarter	16	4	29
New Moon	22	20	43
First Quarter	30	6	6

Mercury. A good opportunity to see Mercury as an evening star will occur on April 12 when the planet will be about 20 degrees from the sun and about 17 degrees above the horizon at sunset.

Venus. Venus will still be visible as a morning star, but is approaching the sun and is quite distant from the earth. The stellar magnitude will be —3.3 throughout the month, and the fraction of the disk illuminaed will vary from 92% to 96%. The apparent diameter will change from 10".96 to 10".22.

Mars. Mars will be moving eastward in Gemini during April. Its distance from the earth will be more than double that at the beginning of the year, and the magnitude will decrease from 1.2 to 1.6. The moon will pass about 3 degrees to the south of Mars on April 28.

Jupiter. Jupiter will complete its westward swing on April 13, and, for the remainder of the year, its motion will be direct. It will move less than a degree in April, and can easily be found just west of the sickle of Leo.

A daylight occultation of Jupiter will occur on April 30. This can be seen with the aid of a telescope, and the times for a few selected places in the United States are as follows:

Place	Immersion h m	Emersion h m
Washington, D. C.	19 46.4	20 59.0
Long. 72° 30', Lat. 42° 30'	19 52.4	21 11.6
Long. 91° 0', Lat. 40° 0'	19 36.2	20 44.4
Long. 120° 0', Lat. 36° 0'	.. ....	20 29.5

Saturn. Saturn will be moving slowly eastward between β and ζ Tauri. The stellar magnitude will be 0.3. The moon will pass 2° 8' to the south of Saturn on April 26.

Uranus. This planet will also be in Taurus. At the beginning of the month, it will be south of 51 and 56 Tauri, and at the end of the month, it will be about two-thirds of a degree south of κ Tauri.

Neptune. Neptune is in Virgo. Its position may be found by the use of the chart of Neptune's path on page 37 of the January issue of POPULAR ASTRONOMY.

Asteroid Notes

By HUGH S. RICE

The only asteroid ephemerides which we have available for the period of March 20 to May 20 are given below. Ceres is now near the Auriga-Gemini border and of visual magnitude approximately 9. The planet 6 Hebe has just passed its opposition to the sun. It is fainter than Ceres, the visual magnitude probably about 10 and within range of 3-inch telescopes. Being near Gamma Leonis, it is in an excellent position for observation. (The ephemerides are furnished by the Yale University Observatory.)

ASTEROID EPHEMERIDES FOR 0h U.T.

1 CERES

1944	α h m	δ ° ′	1944	α h m	δ ° ′
Mar. 21	5 57.6	+29 28	Apr. 5	6 15.7	+29 32
26	6 3.2	+29 31	10	6 22.5	+29 31
31	6 9.2	+29 32	15	6 29.7	+29 29
			20	6 37.2	+29 25
			25	6 44.9	+29 19

6 HEBE

1944	α h m	δ ° ′	1944	α h m	δ ° ′
Mar. 21	10 24.8	+19 2	Apr. 25	10 15.9	+20 27
26	10 21.7	+19 29	30	10 17.0	+20 21
31	10 19.2	+19 52	May 5	10 18.7	+20 11
Apr. 5	10 17.3	+20 8	10	10 20.8	+19 58
10	10 16.0	+20 20	15	10 23.5	+19 43
15	10 15.4	+20 27	20	10 26.6	+19 24
20	10 15.3	+20 29			

Hayden Planetarium, American Museum of Natural History, New York, New York, March 2, 1944.

Occultation Predictions for April, 1944

(Taken from the *American Ephemeris*)

Date 1944	Star	Mag.	IMMERSION Greenwich C.T. h m	IMMERSION a m	IMMERSION b m	IMMERSION Angle E from N °	EMERSION Greenwich C.T. h m	EMERSION a m	EMERSION b m	EMERSION Angle E from N °
OCCULTATIONS VISIBLE IN LONGITUDE +72° 30′, LATITUDE +42° 30′										
Apr. 14	30 G.Sgtr	6.2	7 31.0	−2.0	+1.6	63	8 37.5	−1.5	−0.7	315
15	*o* Sgtr	3.9	6 56.4	−1.2	+1.5	78	8 7.3	−1.3	+0.4	291
26	*m* Taur *m*	5.0	1 33.5	+0.3	−2.3	130	2 14.3	−0.2	0.0	224
27	x^2 Orio	4.7	1 57.6	+0.1	−2.2	127	2 45.7	−0.2	−0.5	238
29	85 Gemi	5.4	4 4.7	−0.9	+0.5	39	4 31.0	+1.0	−3.3	345
30	δ Canc	4.2	2 49.7	−1.0	−1.2	85	3 51.8	0.0	−2.3	311
30	Jupiter	−1.7	19 52.4	−1.2	+0.5	113	21 11.6	−1.6	+1.1	270
OCCULTATIONS VISIBLE IN LONGITUDE +91° 0′, LATITUDE +40° 0′										
Apr. 1	56 Gemi	5.2	4 26.9	−2.0	+1.3	41	5 2.7	+0.5	−4.3	341
14	30 G. Sgtr	6.2	6 59.7	−1.0	+1.2	91	8 11.2	−1.2	+0.4	292
14	14 Sgtr	5.7	11 11.2	−2.1	−0.3	93	12 35.4	−1.8	−0.8	270
15	199 B.Sgtr	6.4	10 54.8	−2.1	+1.2	56	12 8.1	−2.2	−1.0	299
27	x^2 Orio	4.7	2 14.4	..	..	172	2 26.5	..	..	193
28	ζ Gemi (var.)	3.9	4 29.0	−0.1	−1.1	88	5 24.4	+0.4	−1.5	288
29	85 Gemi	5.4	3 50.8	−0.9	−0.8	75	4 47.4	+0.2	−2.3	312
30	δ Canc	4.2	2 31.0	−1.3	−1.8	114	3 48.5	−1.0	−1.8	284
30	Jupiter	−1.7	19 36.2	−0.5	+0.7	111	20 44.4	−0.8	+1.4	266
OCCULTATIONS VISIBLE IN LONGITUDE +120° 0′, LATITUDE +36° 0′										
Apr. 1	56 Gemi	5.2	3 24.6	−2.3	−0.4	91	4 54.3	−1.8	−1.7	286
1	61 Gemi	5.9	6 42.7	−1.0	−0.9	82	7 46.8	−0.1	−2.1	301
12	*x* Ophi	4.8	13 40.3	−1.7	−2.0	132	14 45.3	−1.0	−0.6	248
14	14 Sgtr	5.7	10 17.0	−1.3	0.0	120	11 34.1	−2.2	+0.7	260
15	199 B.Sgtr	6.4	9 58.2	−1.2	+1.2	87	11 12.3	−1.5	+0.5	282
18	39 Aqar	6.2	11 58.7	−1.0	+2.7	31	12 46.5	−1.0	+0.2	300
28	ζ Gemi (var.)	3.9	4 27.8	−0.4	−2.4	132	5 25.9	−0.9	−0.5	248
29	85 Gemi	5.4	3 21.1	−1.4	−2.0	122	4 39.3	−1.5	−1.1	267
29	217 B.Gemi	6.3	6 25.2	−0.9	−0.2	60	7 9.8	+0.5	−2.6	328
30	δ Canc	4.2	2 1.1	..	..	169	2 46.2	..	..	224
30	Jupiter	−1.7	.. ..	..	..	...	20 29.5	+0.1	+1.0	274
OCCULTATIONS VISIBLE IN LONGITUDE +98° 0′, LATITUDE +30° 0′*										
Apr. 1	56 Gemi	5.2	4 15.4	−1.6	−0.9	89	5 29.0	−0.5	−1.8	273
1	61 Gemi	5.9	7 2.2	−0.3	−0.5	71	.. ..	..	..	...
14	30 G.Sgtr	6.2	6 49.9	−0.3	−0.2	129	7 53.4	−1.6	+1.3	258

*Computation by Tecla Combariati and J. Lynn Smith, communicated by Captain J. F. Hellweg, Superintendent U.S. Naval Observatory.

			h	m	m	m	°	h	m	m	m	°
14	14 Sgtr	5.7	11	0.0	—2.4	—0.8	116	12	24.7	—2.3	+0.2	251
15	*o* Sgtr	3.9	6	38.5	+0.5	—1.0	145	7	19.7	—1.3	+2.5	230
15	199 B.Sgtr	6.4	10	29.1	—2.2	+0.9	80	11	57.3	—2.5	—0.2	277
28	ζ Gemi (var.)	3.9	4	40.0	—0.4	—1.4	104	..	..	..	..	...
29	85 Gemi	5.4	3	57.6	—0.7	—1.7	111	5	4.5	—0.3	—1.3	280
30	δ Canc	4.2	2	49.5	—0.6	—4.0	157	3	47.7	—2.2	+0.2	245
30	BD+18°2057m	6.7	6	10.4	—0.6	—0.4	69	..	..	..	..	...
30	Jupiter	—1.7	19	32.8	—0.6	—0.9	141	20	20.2	—0.1	+2.8	233

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

In the following Notes are given the names and addresses of those persons who have added their names to our membership roll since the last was published in May, 1943. The annual report for the Society is now in preparation and should appear in the near future. If any member still has not sent in his 1943 observations, he should do so without delay so that they may be included in the year's total. Also we request that the annual dues be remitted without having to send out bills to each person.

New members:

Kessler, Edwin III, 607 Kinney Avenue, Corpus Christi, Texas.
Weitzenhoffer, Kenneth, 1380 Merriam Ave., New York 52, N. Y.
Mandell, Lewis P., R.F.D. No. 2, Lake Ocewana, Peekskill, N. Y.
Fisher, Donal, Jr., 413 Penn St., Huntington, Pa.
Chlebrukov, Ralph, 457 E. 28 St., Paterson, N. J.
Butler, Corwin, Box 1031, Breckenridge, Texas.
Casey, Wm. L., Box 132, Colmar, Pa.
Arrowsmith, Mrs. A. M., 119-17 179 St., St. Albans 12, L. I., N. Y.
Howe, W. L., 41 Lincoln Ave., Bridgeport 6, Conn.
Hart, A. E., 2903 Easton Ave., Chattanooga 5, Tenn.
Warren, Gerald V., 115 Culbert St., Syracuse, N. Y.
Korchmaros, Jesse, 28 Andrews St., Campbell, Ohio.
Woodburn, Joseph J., Jr., 1921 Pacific St., Philadelphia 40, Pa.
Swoboda, Hubert, 1263 Crooks St., Green Bay, Wis.
Livingston, Robert, Kendall Rd., Churchville, N. Y.
Cypra, Anthony, 97-09 Van Wyck Blvd., Richmond Hill, N. Y.
Trathen, Frank, 2694 Linda Vista Ave., Napa, Calif.
Lenart, Maynard, Fifield, Wis.
Borowitz, S. B., 1392 Shakespeare Ave., The Bronx, N. Y.
Wrinn, John J., Jr., 179 Ward St., Naugatuck, Conn.
Helfer, H. Lawrence, 1592 Jesup St., Bronx 52, New York, N. Y.
Smith, Rev. H. V., Runge, Texas.
Ehman, Chester, 61 Grand St., Hartford 6, Conn.
Schreiner, Miss Leta, R.R. 1, Roosevelt, Okla.

Viertel, William K., 333 S. Pine Ave., South Amboy, N. J.
Olsen, Bruce, 20 Woodland Ave., Port Chester, N. Y.
Nadeau, Paul H., 275 St. Cyrille St., Quebec, Can.

Somewhat fragmentary reports from two places and one regular report by R. M. Dole at Cape Elizabeth, Maine, indicate that the Quadrantids furnished a very good return in the first few days of January, 1944. It is unfortunate that more persons were not on the lookout to profit by the opportunity. At Flower Observatory the study of fireballs with duplicate or multiple reports continues. Cases in considerable numbers are being solved or laid aside as having too incomplete or erroneous data. The larger part of this paper is taken up by a specially important and interesting case.

Fireball of 1932 January 2/3

On this date at 10:28 G.C.T. (January 3) a great fireball was observed from two ships off the California coast and by one person at Santa Paula, California. The former sent in quite complete reports which were published in the *Hydrographic Bulletin, U.S.N.*, while P. V. Stump, the observer, wrote a long letter with two (more or less duplicate) series of drawings of the long-enduring train to Director Adams at Mt. Wilson Observatory by whom it was sent here. It would seem therefore that we have a case which would permit a direct solution in which we might have confidence. The three fireball cards covering the case were taken by Miss E. F. Reilly and a solution attempted. Unfortunately she could not locate Stump's original letter and, finding a total contradiction, she turned her plots, etc., over to me. After some study, freely using our large celestial globe, reading Stump's original letter and examining his drawings, and using my experience in interpreting what casual meteor observers really mean, a solution has been made which I consider fairly good. The two ships' reports will be quoted in full so that my steps will be understandable, but Stump's letter is too long, and the reproduction of his numerous diagrams too difficult for publication. The first will be abstracted, the latter briefly described.

S1. "Sec. Officer G. R. Lauriat . . . Am. S. S. Harpoon . at 1031 G.M.T. (civil in lat. 31° 08′ N, lon. 117° 14′ W, a very bright white meteor . . . appeared near Polaris at an altitude of 29°, bearing 352°, traveled in a S.W. direction, leaving a long white trail which was visible for about 20 seconds, and disappeared in a cloud near the horizon bearing 310° . . . weather partly cloudy. . ." S2. "Sec. Officer J. Pitt . . . Am. S. S. Point Brava . . . at 2:28 A.M. (120th meridian time) in lat. 32° 02′ N, lon. 120° 01′ W, a very bright meteor was observed. The body appeared as a very large ball of fire approximately as large as a full moon, and crossed the sky at an approximate altitude of 40°, from Denebola" (!) [almost certainly Benetnasch is meant. C.P.O.] "towards a point 3° to 4° above Arcturus. Midway between these two stars the body burst into fragments. A short thick trail could be plainly observed for about 15 seconds, indicating the line of passage of the body, and remained visible for 24 minutes, passing through different stages of brightness, shapes and positions. After the meteor burst an apparent globular nucleus of fragments persisted for a minute or a minute and a half. This group of fragments continued to move towards Arcturus, although at a greatly reduced velocity, the color changing meantime to a reddish shade. The disintegrating meteor and trail gradually assumed a crescent shape, brighter at the center, where it still indicated the nucleus of the fragments, then lost this characer and slowly died away . . . atmosphere was clear. . ." S3. Santa Paula, California, lat. 34° 22′ N, lon. 119° 04′ W, 10:25 P.M.,

P.S.T., P. V. Stump observer. Most remarkable meteor seen in life. Afterglow lasted at least 7 minutes . . . "trail was about 25° long and took on four different forms . . . ceased to glow about 10° of the Milky Way and the glow started about 10° S.E. of Leonis. The ring was open on the west side and never closed but spread out into the little cloud about 7° long and 2° wide. This . . . was . . . a whitish color and lasted 2 minutes and kept getting smaller till it disappeared. The first long trail had 3 or 4 colors, red, blue, and bright white and just before it ceased to glow narrowed to a slim neck and then blew up with a lot of sparks. . ."

His diagrams show Jupiter (then near Regulus), Regulus, ρ Leonis and two other stars uncertainly indentifiable, and the Milky Way. They also show the meteor's path and the changes of form of the train. The best I can do is to find the beginning point at $a = 308°$, $h = 62°$, and end at $a = 350°$, $h = 22°$, but the beginning is *most* questionable. The data on the absolute size and relative changes of the train are much more certain. It was at first straight and 20° ± long, lower end (as computed) at 73 km. It then shortened to 8° with downward bulge in middle, then changed to a ¾ circle or horseshoe which was evidently formed by the bulge increasing and ends drawing in, and finally a shape like a plano-convex lens seen edgewise, with long diameter perpendicular to original path and convex side towards end point of path.

Plotting the stations and azimuths therefrom on a map with proper projection, it was found at once that if S2 *really* saw the fireball start at *Denebola* then both the others had the meteor going in the wrong direction. His end point was however satisfactory. He further infers that the path was all the same altitude estimated at 40°. But Denebola had an altitude of 52°, the point above Arcturus, 30°. Nobody could call this an equal-altitude path. Using the globe it was at once found that assuming he meant ζ Urs. Maj. (Benetnasch) *not Denebola,* whose altitude was 38°, this great inconsistency disappeared. As he could not be wrong about Arcturus, and it being improbable that he was in error about the path being horizontal, I have used all altitudes for S2 as 30°. S1 had Polaris very near his beginning point therefore his observation is assumed exact; the end point was not seen by him due to clouds, but his last azimuth checks with my results. S3 diagram gives (what I take to be) the explosion point for the end. I have hence combined this with the exploding point described by S2. This gives an important point on the path. The end point depends on the altitude of S2 alone, but this was very certain and may be relied on. By several approximations and drawing a profile diagram to check, the following results were obtained:

Date	1932 Jan. 2/3 10:28 ± 3, P.M., P.S.T.
Sidereal time at end point	139°.8
Began over	$\lambda = 117°\ 40'$ W, $\phi = 33°\ 38'$ N, at 167 km
Ended over	$\lambda = 119°\ 04'$ W, $\phi = 32°\ 10'$ N, at 50 km
Length of path	229 km
Projected length of path	208 km
Radiant (uncorrected)	$a = 219°$; $h = 28°.6$
Zenith attraction (parabolic heliocentric velocity assumed)	—1°.2
Radiant (corrected)	$a = 219°$; $h = 27°.4$; $\alpha = 228°$, $\delta = +56°$
Top of long-enduring train	118 km
Bottom of long-enduring train	73 km
Top of longest enduring portion	87 km
Bottom of longest enduring portion	73 km
Center of ring formed	80 km

Diameter of ring	11 ±
Greatest bulge of ring from path	9 km towards a = 335°
Dimensions of final cloud (long axis perpendicular to path of meteor)	27 × 7 km

The fireball was recorded as No. 1069 in F.O. Reprint No. 60, but the results there had been derived from inspection and turn out to be partly in error. I request that the corrected results be copied from this paper into both tables of No. 60. Despite the data at hand, only these things can be certainly stated about the train: It was fully included within the usual limits of altitude, the lower part endured longest, the horseshoe endured longest of all and was probably at the point where the explosion occurred, the drift of this was towards a = 335°, the parts above and below were either (a) stationary, (b) drifted parallel to each other slowly towards a = 335°, (c) drifted towards a = 155°. Nothing in the diagrams permit me to choose which is true, but according to S3 the total drift was small everywhere. This means low wind velocities at the moment, but at least 3 different strata are represented at heights of 73, 80, and 87 km, respectively. It is a pity that we have no diagrams or exact descriptions of the changes of shape from S2 who had clear weather and was far closer to the train than the others. S1 had a partly cloudy sky which explains why his duration for the train was so short.

The radiant shows at once that this fireball was a member of the Quadrantid stream, which comes to a maximum on or about the date it appeared. As few data are available on the heights of these meteors and very few have been recorded as having long-enduring trains, this additional case is especially welcome.

In conclusion, though I regret the necessity of having had to manipulate the data I believe they have been correctly interpreted. In any case, reasonable results come from the computation, and the study of the train—unsatisfactory as it may seem—is much more nearly complete than can usually be made.

Flower Observatory, Upper Darby, Pennsylvania, 1944 January 25.

Contributions of the Society for Research on Meteorites

Edited by FREDERICK C. LEONARD
Department of Astronomy, University of California, Los Angeles 24

On the Classification of Meteorites

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ABSTRACT

The classification of meteorites as a whole is briefly presented and discussed; in particular, it is pointed out that the intermediate or transitional group, now universally known as the *siderolites* (symbol, So), consists of 2 main subdivisions, namely the "irony stones," hereinafter termed *sideraerolites* (Sa), and the "stony irons" or so-called *lithosiderites* (Li).

On the basis largely of the Rose-Tschermak-Brezina classification of meteorites,[1] these bodies may be classified in accordance with the following scheme:

CLASSIFICATION OF METEORITES*

Aerolites (symbol, A) = "Stones"
- Achondrites (Ac)
- Chondrites (C)

Siderolites (So) = "Irony Stones" and "Stony Irons"
- Sideraerolites (Sa) = "Irony Stones"
  - Mesosiderites (Ms)
  - Grahamites (Msg)
  - Lodranites (Lo)

- Lithosiderites (Li) = "Stony Irons"
  - Siderophyres (Sy)
  - Pallasites (P)†

Siderites (Si) = "Irons"‡
- { Nickel-poor ataxites
- { Hexahedrites (H)
- { Octahedrites (O) and
- { Intermediate ataxites [called, more rarely, *metabolites*] (D_3§)
- Nickel-rich ataxites (D_1)

NOTES TO THE CLASSIFICATION

*Symbol, Mi.

†4 types.

‡Enumerated, *post*, in the order of increasing percentage of nickel.

§This symbol (D_3) has been adopted to denote that, as regards *frequency of occurrence*, the intermediate ataxites (D_3) are the tertiary class, while the nickel-rich (D_1) and nickel-poor (D_2) varieties are respectively the primary and the secondary type of ataxites.

If meteorites are classified simply as "stones" and "irons," those whose types appear *above* the line drawn between the subdivisions *sideraerolites* (Sa) and *lithosiderites* (Li), under the *siderolites* (So), should be considered as "stones," while those whose types fall *below* the line should be regarded as "irons." In some statistical studies, it is both convenient and justifiable to treat meteorites thus, as being individually either aerolites ("stones") or siderites ("irons"), if for no other reason than that the transitional division of the siderolites ("irony stones" and "stony irons") includes only 4.7% of the classified meteoritic falls of the world.[2] This transitional group, tho comparatively insignificant numerically, is, nevertheless, of fundamental importance mineralogically, and so, in general, should not be merged with the larger divisions of the aerolites and the siderites, but should be differentiated from them. Moreover, because the siderolites constitute the intermediate or transitional group between the aerolites and the siderites, and are characterized by a more or less continuously increasing percentage of nickeliferous iron from one end of their sequence to the other, they logically embrace 2 principal subdivisions, which correspond to the achondrites and the chondrites under the aerolites and to the hexahedrites, the octahedrites, and the ataxites under the siderites. The first subgroup of siderolites, of which the representatives are most closely related to the aerolites, may accordingly be termed *sideraerolites* (symbol, Sa), or "irony stones," while the second subdivision, comprizing the "stony irons," which are most nearly akin to the siderites, may be called, as these "stony irons" have been called for many years, by the appropriate name of *lithosiderites* (symbol, Li). Finally, under the subgroup of the sideraerolites (Sa), as distinct classes come the mesosiderites (Ms), the grahamites (Msg), and the lodranites (Lo), and, under the category of the lithosiderites (Li), the siderophyres (Sy) and 4 different kinds of pallasites (P).[3]

In the Rose-Tschermak-Brezina system of meteoritic classification, as quoted

by Farrington,[4] meteorites are classified under the 2 primary headings of "I. Stones" and "II. Irons." Those specimens herein called "sideraerolites" are placed as "D. Siderolites," under "I. Stones," while the "lithosiderites" are enumerated as "E. Lithosiderites," under "II. Irons." This practice cannot be recommended and should be discontinued, for the sideraerolites and the lithosiderites *together* compose the *transitional* group that is now universally known by the name of *siderolites* and that should be recognized as forming the connecting link in the chain of meteoritic classification between the aerolites on the one side and the siderites on the other, and as being, therefore, in every respect coördinate with those 2 grand divisions of meteorites. According to G. T. Prior,[5] the *siderolites*, as originally defined by N. S. Maskelyne (in 1863) and as now almost everywhere understood, include both the "siderolites" (herein more felicitously termed *sideraerolites*) and the "lithosiderites" of A. Brezina.

In the tabular classification of meteorites at the beginning of this paper, the siderites are arranged in the order of increasing content of nickel. According to W. F. Foshag,[6] hexahedrites (H) contain 6% of nickel; octahedrites (O), 6% to 14%; and ataxites (D), 15% to 30%. This investigator concludes that "The granulation of hexahedrites [H] by secondary heating accounts for the so-called 'low-nickel [= nickel-poor] ataxites' [D_2]."[7] It is interesting to compare the preceding statement concerning the percentages of nickel present in the several varieties of siderites with the following excerpt from Farrington:[8] "A study by the writer[9] of the composition of the iron meteorites showed that a definite relation apparently exists between their composition and structure, or that their composition apparently controls their structure. Thus, the hexahedrites all contain about 6% of nickel, the octahedrites from 7% to 15%, and one group of the ataxites [the nickel-rich ataxites, D_1] a still higher percentage. It appears, therefore, that, in cooling from the original magma, a meteor[it]ic iron which contains 5% to 7% of nickel will crystallize in the cubic form, one containing between 7% and 15% will crystallize in the octahedral form, and one containing a percentage of nickel greater than this will not crystallize at all. Further, among the octahedral irons, the percentage of nickel will influence the width of the [Widmanstätten] bands, the bands being narrower as the percentage of nickel increases." Hence, the chemical composition of a siderite can often be at least approximately inferred from its physical structure—*i.e.*, from its classification—and, conversely, since, between the two, a one-to-one correspondence seems to prevail.

NOTES AND REFERENCES

[1] See O. C. Farrington's *Meteorites*, Ch. 12, 197-204, Chicago, 1915, and 2 papers by the present writer in *C.S.R.M.*, **3**, 65-70 and 81-2; *P. A.*, **51**, 44-9 and 222-3, 1943.

[2] Table 2, *C.S.R.M.*, **3**, 69-70; *P. A.*, **51**, 48-9, 1943.

[3] As a matter of fact, only a *single* example of each of the classes Iodranites (Lo) and siderophyres (Sy) has been recorded, and but *one* of the Bitburg (or Albacher) variety of pallasites (Pb): see the sources referred to in n. (1) and n. (2), *ante*.

[4] *Op. cit.*, n. (1), *ante*, pp. 198-203; in particular, pp. 201-2.

[5] *Catalogue of Meteorites, Brit. Mus. (Nat. Hist.)*, "Introduction," pp. v-ix; in particular, p. viii; London, 1923.

[6] *Am. Mineralogist*, **26**, 137, 1941.

[7] Just as the nickel-poor ataxites (D_2) are probably thermally altered hexahedrites (H), so doubtless are the intermediate ataxites (D_3) mostly, if not all, similarly modified octahedrites (O); *cf.* Prior's remark, *op. cit.*, n. (5), *ante*, p. vii,

and see Farrington, *op. cit.*, n. (1) *ante*, pp. 98-9 and Fig. 43, p. 99.

[8] *Op. cit.*, n. (1), *ante*, pp. 99-100.

[9] *Publ. Field Mus. Nat. Hist., Geol. Ser.*, **3**, 106, Chicago, 1907.

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VARIABLE STARS

Variable Star Notes from the American Association of Variable Star Observers

By LEON CAMPBELL, Recorder

Dutch News on Variable Stars: A recent bulletin issued by the Committee for the Distribution of Astronomical Literature quotes from the *Dutch Astronomical News Letter* No. 1 from Leiden, Holland—dated November, 1943—some notes of interest on variable stars.

RW Tauri, an eclipsing variable with a photographic range exceeding four magnitudes, was under intensive investigation by L. Binnendijk to enable him to derive accurate times of minima for a study of the variable period, as well as the determination of the relative dimensions of the stars and their orbit. All available material between the years 1900 and 1940 was used. The investigation shows that during the past 25 years no sensible change in period has occurred. From the Leiden observations alone, a period of $2^d.7688162$ has been derived. The magnitude varies from 8.00 (phtg.) to 12.27 (phtg.) for the principal minimum. The secondary minimum was not observed.

From an analysis of the light curve the following values were derived. Ratio of radii, 0.690 ± 0.009. Radius of larger star, 0.2495 ± 0.0009, and of smaller star, 0.172 ± 0.004. The smaller component has the greater surface brightness and is totally eclipsed during the principal minimum. The duration of eclipse, from first to last contact, is 0.14 of the period. The computed depth of the secondary minimum is 0^m01.

Two Suspected SS Cygni-type Variables: W. H. Dirks states that he finds two variable stars which appear to belong to the SS Cygni type. Although their amplitudes are small, broad and narrow maxima alternate. One of the stars, situated at 7^h43^m8, $-23° 15'$ (1875), varies between magnitudes 13.1 and 15.1 (phtg.) in cycles of 15 to 23 days. The other, at 7^h49^m, $-24° 00'$ (1875), varies between magnitude 13.8 and 15.8 (phtg.) in cycles of 15 to 20 days. These are the ranges which would be expected for SS Cygni-type stars with such short cycles.

AS Centauri: Miss H. van den Bergh van Eysinga has derived new elements for the W Ursae Majoris variable as follows: Minimum = J.D. $2{,}425{,}025.408 + 0^d.15261844$. The full period of revolution is, of course, double this value. The total range is slightly over 0^m2 (phtg.).

DW Carinae: Miss E. van den Hoven den Genderer presents revised elements for the variable DW Carinae as follows: Minimum = J.D. $2{,}434{,}550.362 +$

$0^d.6638741$. The range is 0^m7 (phtg.) and since no difference could be found between depths of minima, it is assumed that the period of revolution is double that mentioned above.

SZ Camelopardalis: A. J. Wesselink has studied the eclipsing variable SZ Camelopardalis and finds that it is of the β Lyrae type with a period of 2.7 days. The two minima have amplitudes of 0^m27 and 0^m22 (phtg.), respectively. The variable itself is the northern component of the visual double Σ 485. The southern component of the double was used as a comparison star, magnitude 7.0 (Potsdam), and both variable and companion star are of spectral type B0, and their color indices are 0^m6, which indicates considerable selective galactic absorption. The observations were made with a Schilt photometer. A period of $2^d.6984166 \pm 0^d.0000033$ was derived. The separation between primary and secondary minima is 0.4990 of the whole period.

Variables in Messier 5: P. Th. Oosterhoff has studied the variables in M 5 from 81 plates taken at the Mount Wilson Observatory on 15 nights in 1934-35. The plates were "blinked" and 88 variables were detected, 11 of which are new ones. As some of the variables announced by Bailey in this cluster proved not to be variable, the total number of variables is now listed at 97.

The median magnitude for the variables measured in the Schilt photometer is:

$$\begin{aligned} a \text{ and } b \text{ type} &= 15^m024 \\ c \text{ type} &= 15.037 \\ \text{all} &= 15.028 \end{aligned}$$

Similar values for *all,* derived by Bailey and Shapley, were 14^m95 and 15^m26, respectively.

Oosterhoff investigated the secular variations in the periods of 41 variables of the *a* and *b* types, which give a mean value of β, the fraction with which the period increases in the course of one period, as $10^u \times 15 \pm 12$ (m.e.). Contrary to the result obtained by Martin for ω Centauri, there is no evidence of a preferential lengthening of periods in M 5.

In a comparison of frequency distribution of periods in M 5 and ω Centauri it is found that the distributions would be similar if a shortening of all the periods in ω Centauri by 15 per cent were made.

Maximum 335 of SS Cygni: With an interval of 96 days between successive rises to maximum, the 335th rise to maximum of SS Cygni was observed by D. W. Rosebrugh early in February. Five maxima were observed in 1942 and the same number in 1943. The average length of cycle for these years was 70 and 79 days, respectively, whereas the average period has been reckoned as about 50 days.

Accordingly, to find two cycles of over 90 days in the same year is of real interest. Of all the variables of this type, SS Cygni certainly presents the greatest enigma.

Maximum of o Ceti, 1944: As pointed out in these notes for January, 1940, a retarded rise to magnitude 6.0 on the increase to maximum of o Ceti is generally associated with a relatively faint magnitude at that maximum. The interval between the present rise and the one just preceding it, is of the order of 346 days, some 15 days longer than the average of 331 days, and it now looks as though the maximum magnitude would not exceed four. This appears to be a further substantiation of the statement made above.

Observers and Observations for January, 1944:

Observer	No. Var.	No. Ests.	Observer	No. Var.	No. Ests.
Blunck	12	12	Meek	36	187
Boone	5	5	Nadeau	94	100
Bouton	9	10	Oheim	10	18
Buckstaff	15	25	Oravec	8	34
Fernald	66	111	Parks	16	22
Ford	25	25	Peltier	119	177
Harris	6	6	Robinson	37	74
Hartmann	111	115	Rosebrugh	17	115
Holt	100	162	Schoenke	38	91
Howarth	16	16	Segers	11	44
Irland	15	15	Sill	50	50
Kearons	91	151	Vohman	15	16
Kelly	13	17	Webb	10	11
Luft	4	7	Weber	22	22
Manlin	49	49	—		—
Mary	6	6	30	(total)	1693

February 18, 1944.

Comet Notes

By VAN BIESBROECK

There are at this time no comets known to be visible with ordinary telescopes.

Several faint objects mentioned previously are no longer observable.

Comet van Gent-Peltier-Diamaca. From a delayed report that came through Copenhagen it appears that this comet was independently found, one day after Peltier's discovery, by Diamaca in Rumania. Thus it will be designated under the three names above. As was expected, the brightness dropped rapidly in the second half of January, but this decrease went much faster than anticipated. On January 15 the comet appeared as a very diffuse coma, some 2′ in diameter with a suggestion of a short tail in 85°. The brightness was then reduced to magnitude 13. Soon the coma became even less distinct while it still faded further in intensity. The last record obtained here was on January 24. The magnitude was only 15.5 then and the vague nebulosity was hardly measurable any more. The comet was then at low altitude after sunset and it is improbable that other observations were made elsewhere after that date. This put an end to a period of visibility of only 58 days.

Periodic Comet d'Arrest was lost in the evening sky about the same time. On January 15 I recorded it as a vague coma as faint as magnitude 16.5. A week later only a suggestion of a poorly defined coma was left and it had dropped one magnitude in the meantime. The observations at this return therefore cover a period of 89 days.

In another of its unpredictable surges of brightness Comet Schwassmann-Wachmann No. 1 has risen to magnitude 13 on January 18 after remaining as faint as of magnitude 17 or even 18 in December. It showed a sharp core surrounded by a coma about 4′ in diameter. It remained several days in that shape while gradually fading: January 21 = 13.5 mag., January 24 = 14 mag., February 19 = 15.5 mag. On this last date the central condensation was much less pronounced. No further observations were secured on this curious object

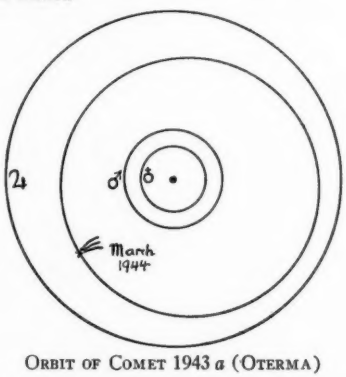
which is now also vanishing in the western sky. Periodic Comet Comas Solá has remained practically unchanged in January and February. It showed a neat little tail about 2′ long emerging from a well-defined nucleus; the total brightness corresponded to a star of magnitude 13.5. It will remain observable for some time yet, following closely the ephemeris that is continued here from the January report.

Ephemeris of Periodic Comet Comas Solá

Date 1944	α h m	δ ° ′
Mar. 27	4 12.4	+27 16
Apr. 4	33.9	28 37
12	4 56.4	29 45
20	5 19.8	30 38
Apr. 28	5 43.8	31 18
May 6	6 08.3	+31 41

It comes closest to the sun on April 11 but its distance from the earth is steadily increasing so that the apparent brightness is expected to change little during the period over which the ephemeris extends.

Periodic Comets Schaumasse and Daniel 1909 IV are apparently going to escape detection at the present return. It is true that a rediscovery of the latter was announced by an English amateur, but this remained unconfirmed. Neither do my photographic records show the presence in the presumed field nor has an elaborate search of the region by such an experienced hunter as L. Peltier revealed anything of the comet.



Orbit of Comet 1943 *a* (Oterma)

Before the end of January I succeeded in locating the Comet 1943 *a* (Oterma) which now has made its reappearance in the morning sky. The first record was obtained January 23 and further measures were secured later on. Although quite faint (16.5 mag.) this little object is of unusual interest in that the eccentricity of its orbits is as small as 0.14, a value smaller than that of the orbit of Mercury and identical to that of the often-mentioned and yearly-observed Comet Schwassmann-Wachmann No. 1. But while the orbit of the latter, corresponding to a period of 16 years, is situated between the paths of Jupiter and Saturn, periodic comet Oterma remains in the region of the asteroids between Jupiter and Mars. The elements given in Popular Astronomy, **51**, 463 (1943) indicate a period of nearly 8 years. The diagram shows the location of the comet among the planetary

orbits. The sun is represented by the central black dot surrounded by the orbits of the Earth and Mars; the outer circle represents the orbit of Jupiter. Considering the distance relations the brightness should not undergo very great changes which makes it very probable that visibility will extend over the whole orbit as in the case of an asteroid. The question arises at once if its light will remain steady or exhibit such violent fluctuations as are shown by Comet Schwassmann-Wachmann No. 1, which is so far unique in that respect. Only further careful watching can answer the question.

Williams Bay, March 1, 1944.

Book Reviews

Spherographical Navigation, by Dirk Brouwer, F. W. Keator, and Drury A. McMillen. (The Macmillan Company, New York, 1944. $5.00.)

This book is a manual of instruction on a system of celestial navigation called Spherographical Navigation. While the system is based upon principles which are of considerable antiquity, it is new in the sense of its instrumentation and in its practical application to the solving of the problem of position. Reduced to its simplest terms, the Spherographical System embodies the use of a spherical plotting surface on which a fix of position is obtained by the direct plotting of the altitudes of selected celestial bodies. Practically no calculations are required; and no tables are necessary except the *American Air Almanac* or the *Nautical Almanac*. No solution of the spherical triangle is made for the computed altitude based upon either the dead reckoning position or an assumed position.

Aside from the simplification of the solution provided by the method, and the speed with which a solution can be obtained, a distinct advantage lies in the ease with which it can be learned. This is very largely due to the fact that the learner has a visual picture of his problem before him at all times. The beginner, without previous training in celestial navigation, can learn the method in approximately three weeks' time; an accomplished navigator can acquaint himself with the operation of the instruments and the methods of construction in a few hours. Accuracy of solution is attained only with practice in using the instruments, and this will be necessary for both the beginner and the full-fledged navigator. *(From the Publisher's notice.)*

Star Maps for Beginners, by I. M. Levitt and Roy K. Marshall. (May be obtained from the authors at The Franklin Institute, Philadelphia, Pa., at 50 cents a copy, postpaid.)

To a person looking casually at the starry sky the objects he sees seem to be scattered there at random and in hopeless confusion. Until he gives some thought to the question he is hardly aware of the fact that the stars maintain their relative positions from year to year with a fidelity which is equalled by few terrestrial phenomena. When one sets out to bring order out of seeming confusion, he needs a teacher or some other help. Many maps of the sky have been published and many devices invented to facilitate the undertaking to become acquainted with the stars. The maps mentioned above are among the most recent and among the best suited for the purpose.

The pamphlet consists of 32 pages of convenient size. The first pages are devoted to the historical development of the constellations as they are known today. This is presented in a very readable form touching the salient facts but unencumbered by non-essential details. After a reading of these pages one feels that he has already entered upon a study of the extensive science of astronomy.

After the constellations, the planets, which are in a different category and require different treatment, are discussed, and a device is given for locating those which are visible to the naked-eye among the stars. The explanations are clear and concise.

Then follows a series of twelve full-page maps, each in four parts, one for each of the points of the compass, north, south, east, and west. On the page facing each map are found pertinent comments concerning the maps and calling attention to the particular features on them. Interspersed with the descriptions of the maps are references to the numerous mythological legends which are associated with the constellations. All of this affords most interesting and informative reading.

To a beginner in the study of astronomy the writer could not suggest a more profitable investment than the purchase of this set of maps.—C.H.G.

The Astronomical Tables of the Maya. This is the title of an octavo pamphlet of some thirty pages by Maud Worcester Makemson of Vassar College. It is number 42 in the series of "Contributions to American Anthropology and History." As a consequence of her study of the various tables presented, the author makes the following deduction:

"The evidence of the eclipse calendar, the Venus ephemeris, the absence of Mars tables, and the method of predicting equinoxes and solstices, all points definitely to the conclusion that Maya astronomers were not concerned with the exact times when astronomical phenomena occurred, except when these times coincided with certain significant days of the tzolkin."

Pages missing here were advertisements and have been removed so that the volume will not be too bulky.